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Performance Tests of Four Selected Oil Spill Skimmers

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Performance Tests of Four Selected Oil Spill Skimmers

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16. ABSTRACT

A series of performance tests were conducted at the U.S. Environmental Protection Agency's OHMSETT test facility with four selected oil spill pickup devices (skimmers). Each of the four skimmers was tested for two weeks with both high and low viscosity oils.

The objectives of the tests were to establish the range of best performance for each skimmer under the manufacturer's design limits and to document test results on 16mm film and by quantitative measures of performance.

The four oil skimmers studied by the OHMSETT Interagency Test Committee were: 1) Oil Mop Skimmer - A catamaran vessel designed primarily for oil skimming at speeds above 1.5 m/s. 2) Cyclonet 050 - A device mounted on an inflatable boat designed for oil skimming in relatively calm water. 3) Clowsor Skimmer - A unit designed primarily for recovering oil at very high rates while held stationary in calm water. 4) Bennett Mark 6E - A semi-catamaran vessel designed for skimming oil at speeds up to 1.5 m/s.

A total of 198 individual data test runs were made during the course of the 8-week test program. Each skimmer was tested to the limit of its design conditions and beyond.

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PERFORMANCE TESTS OF FOUR SELECTED OIL SPILL SKIMMERS

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DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views or policies of the OHMSETT Interagency Test Committee or its member organizations, the U.S. Environmental Protection Agency, the U.S. Coast Guard, the U.S. Department of Energy, and the U.S. Navy, nor does mention of trade names or commercial products constitute endorsement or recommendation for use, nor does failure to mention or test other commercial products indicate that other commercial products are not available or cannot perform similarly well as those mentioned.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes performance evaluation tests of four oil skimmers. This report will be of interest to all those interested in cleaning up oil spills in inland and coastal waters. Further information may be obtained through the Resource Extraction and Handling Division, Oil and Hazardous Materials Spills Branch, Edison, New Jersey.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

In February, 1977, representatives of the United States Environmental Protection Agency, Coast Guard, Navy, and Department of Energy met to form an OHMSETT Interagency Test Committee (OITC) for the purpose of sponsoring tests of selected oil pollution control equipment at the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) facility in Leonardo, New Jersey. The primary motivations in forming the OITC were:

(a) To combine funds to study equipment of joint interest.
(b) To provide a formal focal point for interagency discussion and comparison of oil pollution abatement programs.

Other interested U.S. and Canadian agencies have been invited to participate in committee discussions, offer recommendations for selection of test equipment, and share in test data results.

This report describes the performance testing of four selected commercial off-the-shelf oil spill pickup devices. In addition to the complete technical details contained in this written report, a 16 mm narrated motion picture report has also been prepared which shows the dynamic nature of selected test runs and a summary of test results.

As public agencies, the sponsors of this work hope that the test results generated under this program can be utilized not only within their own agencies but also by the public.

ABSTRACT

A series of performance tests were conducted at the U.S. Environmental Protection Agency's OHMSETT test facility with four selected oil spill pickup devices (skimmers). A description of the OHMSETT facility is presented in Appendix A. Each of the four skimmers was tested for two weeks with both high and low viscosity oils. Selection of the four test skimmers depended on the satisfaction of the following criteria:

(a) Commercial hardware must have either never before tested at OHMSETT, or have a significant improvement over similar previously tested equipment.

(b) Equipment must be of significant interest to at least one of the Test Committee sponsoring agencies.

(c) Manufacturer must be willing to lend the equipment for testing at no charge to the government.

The objectives of the tests were not to compare skimmers with one another, but to establish the range of best performance for each skimmer under the manufacturer's design limits and to document test results on 16 mm film and by quantitative measures of performance.

The four oil skimmers studied by the Test Committee during the OHMSETT 1977 season were, in order of testing:

(1) Oil Mop ZRV Skimmer. A catamaran vessel designed primarily for oil skimming at speeds above 1.5 m/s.

(2) Cyclonet 050. A device mounted on an inflatable boat designed for oil skimming in relatively calm water.

(3) Clowsor Skimmer. A unit designed primarily for recovering oil at very high rates while held stationary in calm water.

(4) Bennett Mark 6E. A semi-catamaran vessel designed for skimming oil at speeds up to 1.5 m/s.

A total of 198 individual data test runs were made during the course of the 8-week test program. Each skimmer was tested to the limit of its design conditions and beyond, in order to confirm the limit of effective oil slick pickup. Considerable quantitative data were obtained for each skimmer and are discussed in separate sections of this report. In reviewing the test results for each skimmer, it should be kept in

mind that trends, or rates of change, of test results are often more important than the numerical value of individual data points. These trends show to what extent changing environmental conditions may affect performance.

A motion picture report entitled "Performance Testing of Four Selected Oil Skimmers" is an important adjunct to this report and illustrates the dynamic response of each skimmer to selected test tank conditions.

This report was submitted in fulfillment of Contract No. 68-03-0490, Job Order No. 32, by Mason & Hanger-Silas Mason Co., Inc. under the sponsorship of the U.S. Environmental Protection Agency, U.S. Coast Guard, U.S. Department of Energy, and U.S. Navy. Technical direction was subcontracted to Pollution Abatement Associates. This report covers a period from April 18, 1977 to October 28, 1977, and work was completed as of December 15, 1977.

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ABBREVIATIONS

m	--metres
mm	--millimetres
m^3	--cubic metres
m/s	--metres per second
m^2/s	-square metres per second
m^3/s	--cubic metres per second
s	--seconds
V_{oil}	--oil collected by skimmer during steady state test time (m^3)
t_{ss}	--steady state test time (s)
V_T	--total oil/water mixture collected by skimmer during steady state test time (m^3)
Q_o	--rate at which test oil enters the front of the skimmer (m^3/s)
ND	--No Data
HC	--Harbor Chop wave condition. A non-regular wave condition achieved by allowing waves to reflect off all tank side walls
OHMSETT	--Oil and Hazardous Materials Simulated Environmental Test Tank
OITC	--OHMSETT Interagency Test Committee
ORR = $\frac{V_{oil}}{t_{ss}}$	--Oil Recovery Rate = volume of oil recovered by the skimmer per unit time during steady state test (m^3/s)
RE = $\frac{V_{oil}}{V_T}$ x 100	--Recovery Efficiency = percent oil in the oil/water mixture being recovered from the water surface by the skimmer (%)
TE = $\frac{V_{oil}}{Q_o t_{ss}}$	--Throughput Efficiency = percent of oil entering the skimmer which is recovered from the water surface by the skimmer (%)

CONVERSION FACTORS

METRIC TO ENGLISH

To convert from	to	Multiply by
Celsius	degree Fahrenheit	$t_C = (t_F-32)/1.8$
joule	erg	1.000 E+07
joule	foot-pound-force	7.374 E-01
kilogram	pound-mass (lbm avoir)	2.205 E+00
metre	foot	3.281 E+00
metre	inch	3.937 E+01
$metre^2$	$foot^2$	1.076 E+01
$metre^2$	$inch^2$	1.549 E+03
$metre^3$	gallon (U.S. liquid)	2.642 E+02
$metre^3$	litre	1.000 E+03
metre/second	foot/minute	1.969 E+02
metre/second	knot	1.944 E+00
$metre^2$/second	centistoke	1.000 E+06
$metre^3$/second	$foot^3$/minute	2.119 E+03
$metre^3$/second	gallon (U.S. liquid)/minute	1.587 E+04
newton	pound-force (lbf avoir)	2.248 E-01
watt	horsepower (550 ft lbf/s)	1.341 E-03

ENGLISH TO METRIC

centistoke	$metre^2$/second	1.000 E-06
degree Fahrenheit	Celsius	$t_C = (t_F-32)/1.8$
erg	joule	1.000 E-07
foot	metre	3.048 E-01
$foot^2$	$metre^2$	9.290 E-02
foot/minute	metre/second	5.080 E-03
$foot^3$/minute	$metre^3$/second	4.719 E-04
foot-pound-force	joule	1.356 E+00
gallon (U.S. liquid)	$metre^3$	3.785 E-03
gallon (U.S. liquid)/ minute	$metre^3$/second	6.309 E-05
horsepower (550 ft lbf/s)	watt	7.457 E+02
inch	metre	2.540 E-02
$inch^2$	$metre^2$	6.452 E-04
knot (international)	metre/second	5.144 E-01
litre	$metre^3$	1.000 E-03
pound-force (lbf avoir)	newton	4.448 E+00
pound-mass (lbm avoir)	kilogram	4.535 E-01

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Mr. John S. Farlow, the OHMSETT Project Officer for the Environmental Protection Agency, served as the OHMSETT Interagency Test Committee (OITC) Chairman and provided valuable assistance throughout the project.

Mason & Hanger-Silas Mason Co., Inc., the operating contractor for OHMSETT, deserves a special note of thanks for the professional and innovative support of their personnel at the OHMSETT test site. Mr. R.A. Ackerman, General Manager, Mr. M.G. Johnson, Test Director, and the Test Engineers, H.W. Lichte and M.K. Breslin, provided continual guidance and assistance throughout the test program concerning detailed test procedures and sequence to maximize the number of data runs obtained.

In the areas of data collection and reduction, Mr. G.F. Smith was especially helpful in the laboratory measurement of numerous oil/water samples and the reduction of this raw data into graphic form.

Videotape coverage, a key element in making real time decisions between test runs, 16 mm photography for the motion picture, and 35 mm photography for the written report were amply carried out in spite of the usual difficulties of weather and electronic malfunctions by the OHMSETT photo/video electronics department.

Funds for this project were provided by the OHMSETT Interagency Test Committee (OITC) comprised of the U.S. Environmental Protection Agency, the U.S. Department of Energy, the U.S. Coast Guard, and the U.S. Navy.

SECTION 1

PROJECT OBJECTIVES

The objectives of the 1977 OITC-sponsored OHMSETT tests were threefold:

(1) Collect quantitative performance data of skimmer operation over a wide range of wave conditions, tow speeds, and oil types.

(2) Determine a range of best performance for each oil skimmer.

(3) Identify equipment modifications which may increase skimmer performance.

These objectives were accomplished for each of the four selected skimmers by conducting the test series described in the individual skimmer sections of this report.

Three techniques were important to ensure good test data. First, for each skimmer, initial test runs involving many oil/water samples were conducted to ensure that performance data was being taken only after steady state conditions had developed after start up of the test run. Second, while conducting these tests repeatability of the measured data was of primary concern. In some cases, a number of reruns were conducted to confirm repeatability. Third, every effort was made to ensure that all of the test oil slick entered the mouth of the skimmer to reduce the uncertainty in determining the oil volume actually encountered during the test run.

The following three performance parameters were determined for each individual test run (see also Abbreviations):

(1) THROUGHPUT EFFICIENCY (TE). Percentage of oil entering the skimmer which is picked up.

(2) RECOVERY EFFICIENCY (RE). Percent oil in the oil/water mixture picked up by the skimmer.

(3) OIL RECOVERY RATE (ORR). Volume of oil recovered by the skimmer per unit time during steady state operation.

During the course of data analysis it also became clear that the trend of the above three parameters with variations of tow speed, wave

condition, and oil type is at least as important as the numerical values in determining the range of applicability of a given skimmer.

Each of the following four sections is a complete and self-contained description of test procedures, conditions, results, and trends of results with changes in conditions for each of the four skimmers tested. It should be kept in mind that each skimmer is designed to operate most effectively in a different range of environmental conditions; therefore, direct comparison of one skimmer with another is not always possible.

Four Appendices are attached to this report and present, in turn, a description of the OHMSETT facility, properties of the test oils used for each skimmer test, descriptive brochures for each skimmer, and sampling procedures.

SECTION 2

OIL MOP ZRV SKIMMER

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

During the period 18 to 29 April 1977, 44 oil pickup performance data runs were conducted with the Oil Mop ZRV skimmer. A total of 17 tests were conducted with high viscosity (heavy) oil and 27 tests using low viscosity (light) oil[1].

Best performance--

The highest average values of the three skimmer performance parameters, TE, RE, and ORR, for each of the heavy and light oil tests are summarized in Tables 1 and 2.

TABLE 1. HIGHEST AVERAGE RESULTS - OIL MOP ZRV (HEAVY OIL)

Performance parameter	Highest average result	Tow speed m/s	Wave condition ht x length (m x m)
TE	71%	0.5	0
RE	77%	1.0	0
ORR	3.6 (x $10^{-3}m^3/s$)	1.5	0

TABLE 2. HIGHEST AVERAGE RESULTS - OIL MOP ZRV (LIGHT OIL)

Performance parameter	Highest average result	Tow speed m/s	Wave condition ht x length (m x m)
TE	78%	1.0	0
RE	70%	1.0	0
ORR	4.8 (x $10^{-3}m^3/s$)	2.0	0

[1]Physical properties of both test oils are listed in Appendix C for each skimmer test.

The above values are the highest averages of all individual test results at the same test tank conditions. Although certain test results may be higher than the values listed above, the use of an average is more representative of the true value since it compensates for random experimental errors.

For an overall conclusion of the trends of the above three skimmer performance parameters, the average values of results are plotted for each test tank condition tested.

Operating Limits--

Based upon the behavior observed in these tests, the operating limits for this skimmer appear to depend upon three factors:

(1) Mechanical design of the bow mop wringer and stern roller assemblies.

(2) Contact time between oil slick and mops as the skimmer travels over the slick.

(3) Large surface area of the drip pan between stern rollers and bow wringer.

Regarding the first item, the bow wringer assembly was unable to rotate the mops with heavy oil at speeds faster than 1.5 m/s without jamming, due to mop strands adhering to the squeeze rollers. Following the conclusion of this test series, the manufacturer resolved this problem through a redesign of the bow wringer assembly. Oil loss occurred in light oil tests in the form of a rooster tail as the mops were pulled aboard the skimmer over the stern roller at forward speeds above 1.5 m/s.

Regarding the second factor, the oil contact time limits the pickup rate of oil at high skimmer forward speeds. The number of test runs was insufficient to establish this upper speed limit precisely. The maximum speed for which data was obtained was 2.5 m/s. At skimmer forward speeds of 2.5 m/s, the oil-to-mop contact time is only 4.8 seconds between the bow and stern of the 11.7 m long catamaran where the mops are lifted out of the water.

Oil loss from the third factor was noted during tests with heavy oil. The loss was caused by slippage of the mops over the squeeze rollers at the bow due to the large drag of the oil-laden mops against the drip pan as they were pulled forward by the bow wringer assembly.

Mechanical Problems--

Mechanical difficulties were encountered with the mop wringer assembly on the bow, the drain pan between bow and stern, and the stern rollers. The bow mop wringer jammed frequently when operating with heavy oil and a 25 cm diameter mop. The jamming with the mop and heavy

oil was due to individual strands of the mop which would stick to the roller after being squeezed, thus dragging the mop around the roller causing a jam. A number of field modifications were attempted (see Discussion paragraph), but without success. The problem was reduced somewhat with the substitution of a thinner 15 cm diameter mop for the 25 cm diameter one. All heavy oil tests were run with the thinner 15 cm diameter mop. However, the tendency to jam was still present above a 1.5 m/s tow speed. Also, in heavy oil tests, the cumulative drag of the six oil-laden 15 cm mops against the return pan caused slippage of the mops against the squeezing rollers above 1.5 m/s tow speeds. It was necessary to install a set of nonpowered rollers stretching across the return pan to lift the saturated mops off the pan before the bow wringer assembly could pull the mops forward without slippage. A splash cover on the stern roller assembly was added to prevent loss of light oil via the rooster tail phenomena at speeds above 1.5 m/s. The presence of deck level engine hatches caused take up of water in the engine compartments during some wave tests.

Recommendations

None of the mechanical problems mentioned in the Conclusions section above are serious. All have been passed on to the equipment manufacturer and have been considered in the design of subsequent Oil Mop units. It is recommended that the Oil Mop ZRV skimmer, complete with modifications to eliminate the mechanical problems discussed above, be retested at OHMSETT.

SKIMMER DESCRIPTION

The Oil Mop ZRV skimmer as manufactured by Oil Mop, Incorporated, of Belle Chasse, Louisiana, is a self-propelled catamaran vessel, 11.6 m in length with a 3.7 m beam, designed to be operated by a crew of two. Other technical specifications are presented in the brochure in Appendix D. As an oil slick enters the space between the catamaran hulls from the right, it is contacted by one of six floating polypropylene brush-like ropes called mops. The mops are rotated at a speed equal to the forward way of the skimmer so that a zero relative velocity condition is achieved. The oil in the slick is sorbed onto the surface of the many flexible strands of the mop as the skimmer moves over the oil slick. After the skimmer has passed a fixed point in the oil slick, the mops are lifted out of the water, up over a stern roller assembly, and pulled along a flat return tray running the length of the vessel by a powered squeeze wringer assembly at the bow. Here the oil is squeezed out of the mops and drops by gravity into a tray below, where it is pumped off the skimmer by two positive displacement Tuthill lobe pumps. The total pumping capacity of these two pumps is $17.7 \times 10^{-3} m^3/s$, although in these tests with 3 mm thick oil slicks, the maximum average offloading rate observed was $4.98 \times 10^{-3} m^3/s$ with light oil. Two diesel prime movers, one in the stern of each catamaran hull, drive the outboard propulsion (not used for these tests) and the various hydrualic motors which operate the bow wringer assembly and the Tuthill offloading pumps. The two hydraulically actuated wringer assemblies are mounted on the

bow. Each provides rotational and squeezing power for a gang of three mops. Figures 1, 2, and 3 show the device under test at OHMSETT as well as its operating principle and above-mentioned wringer assemblies.

Figure 1. Oil Mop Inc. ZRV under test.

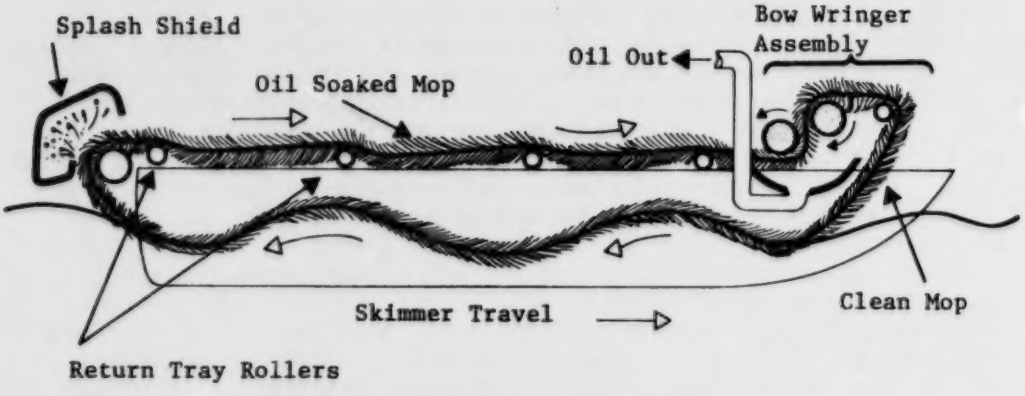


Figure 2. Oil Mop Inc. ZRV schematic.

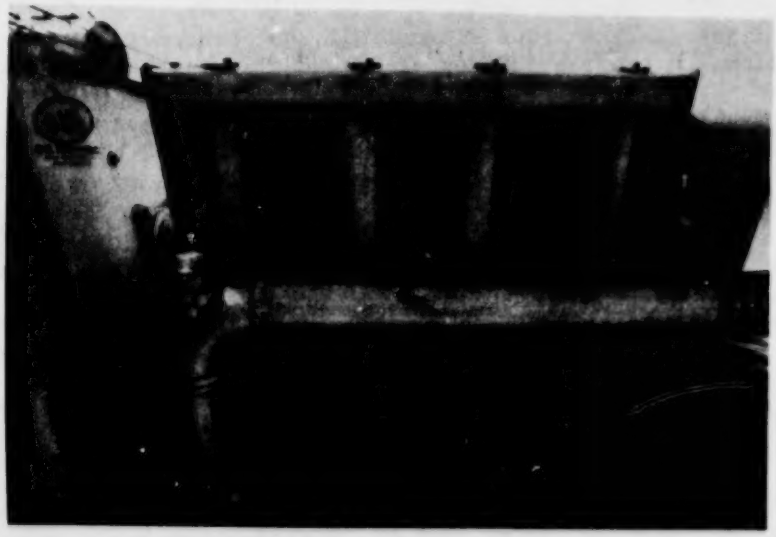


Figure 3. Oil Mop Inc. ZRV bow wringers.

TEST MATRIX AND PROCEDURES

Test Matrix

Initial checkout tests were conducted to establish the maximum operating wave and tow speed conditions under which oil collection tests were to be conducted and to evaluate various sampling procedures. The performance tests for both heavy and light oils were then conducted in accordance with the matrix of test conditions itemized in Table 3.

TABLE 3. TEST MATRIX - OIL MOP ZRV

Test mode	Tow speed (m/s)	Slick thk. (mm)	Waves (m x m)	Test oil
Towed	0.5	3	0	Heavy
Towed	1.0	3	0	Heavy
Towed	1.5	3	0	Heavy
Towed	1.5	3	0	Heavy
Towed	0.5	3	0.6 HC	Heavy
Towed	1.0	3	0	Light
Towed	2.0	3	0	Light
Towed	2.5	3	0	Light
Towed	1.0	3	0.6 HC	Light
Towed	2.0	3	0.6 HC	Light
Towed	2.5	3	0.6 HC	Light
Towed	1.0	3	0.8 x 12.4	Light
Towed	2.0	3	0.8 x 12.4	Light

Procedures

For initial checkout runs without oil, the procedure was to set the wave condition and tow the skimmer at a gradually increasing speed from 1 to 3 m/s. Skimmer response was noted in tape recorded comments by the test engineers and photographed with 35 mm and above water video cameras. These taped comments and replay of the videotape formed the basis for establishing the maximum tow speed and wave conditions to be used for subsequent oil performance tests.

All oil performance tests under the test conditions of Table 3 were conducted using the procedure itemized in Table 4. Appendix B gives sampling procedures, and Appendix C lists test oil properties.

TABLE 4. TEST PROCEDURES - OIL MOP ZRV

1.	Pump dry the mop wringer sumps and skimmer-to-collection barrel with the onboard positive displacement pumps.
2.	Accelerate skimmer up to test speed; at a predetermined mark along the tank, start test oil distribution.
3.	When test oil slick reaches the skimmer bow, activate mop rotation, skimmer pumps, and a stopwatch. During the run, obtain grab samples from the pump discharge at intervals ranging from 5 seconds at the beginning of the run to 15 seconds near the end of the run. Shut off test oil distribution at a predetermined spot and continue towing for two additional vessel lengths, or 24 metres. At this point, stop mop rotation but leave the offloading pumps operating.
4.	When all fluid has been pumped from the mop wringer sumps into the collection barrels, stop the offloading pumps and stopwatch.
5.	Using squeegees, scrape any oil in the drip tray into the mop wringer sumps. Pump this fluid into the collection barrels, timing the pump activation required. Record the total elasped time the offloading pumps were operating.

TEST RESULTS AND DISCUSSION

Test Results

Results of the performance parameters TE (Throughput Efficiency) and RE (Recovery Efficiency) are plotted in Figures 4 and 5.

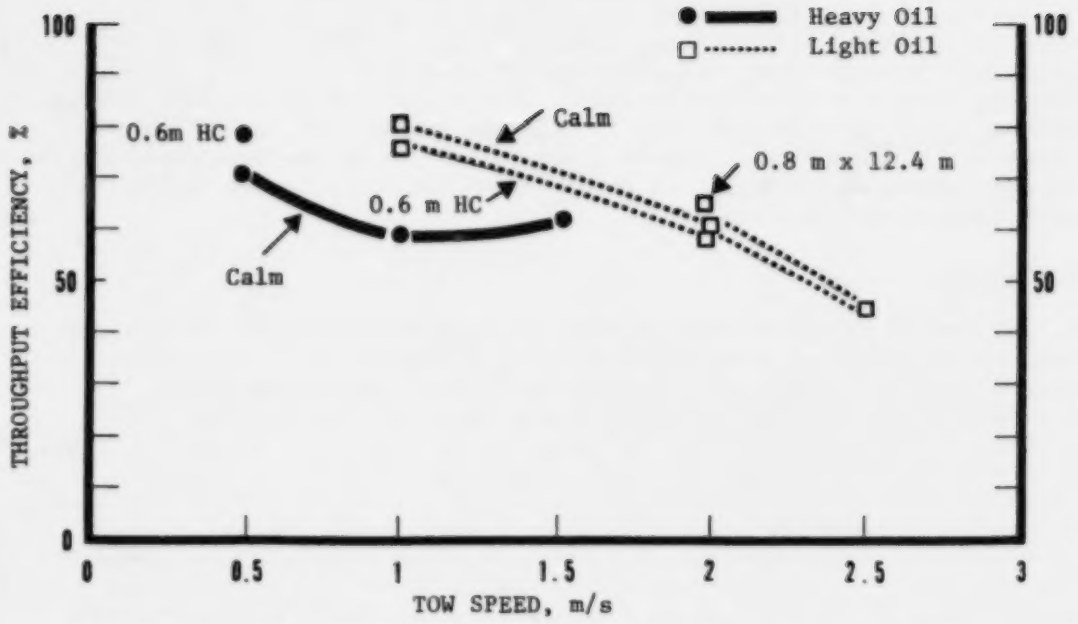


Figure 4. Throughput efficiency trends - Oil Mop Inc. ZRV.

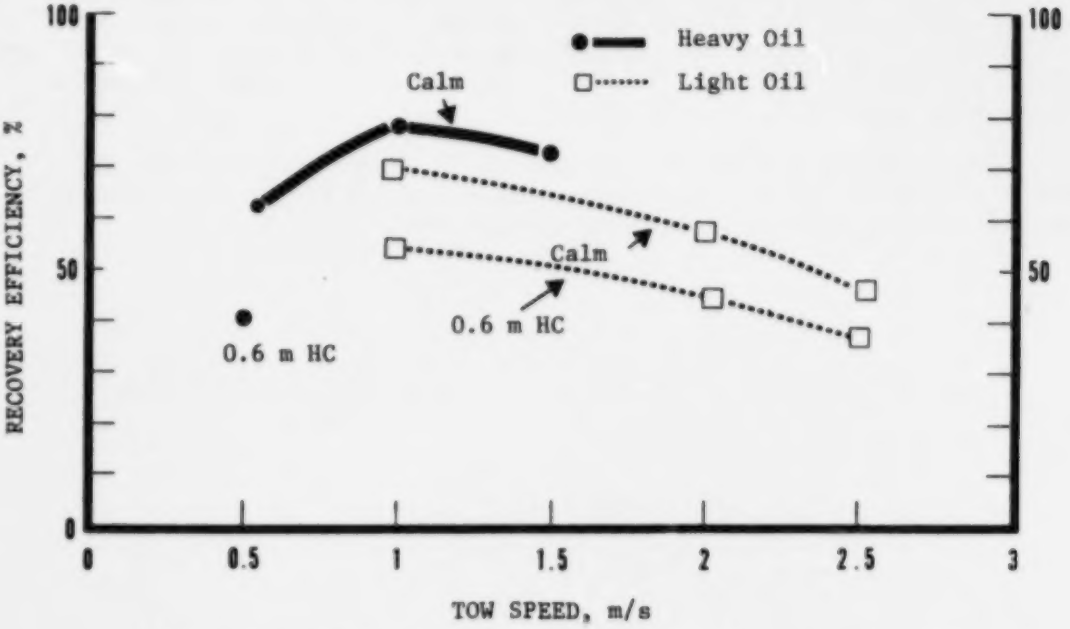


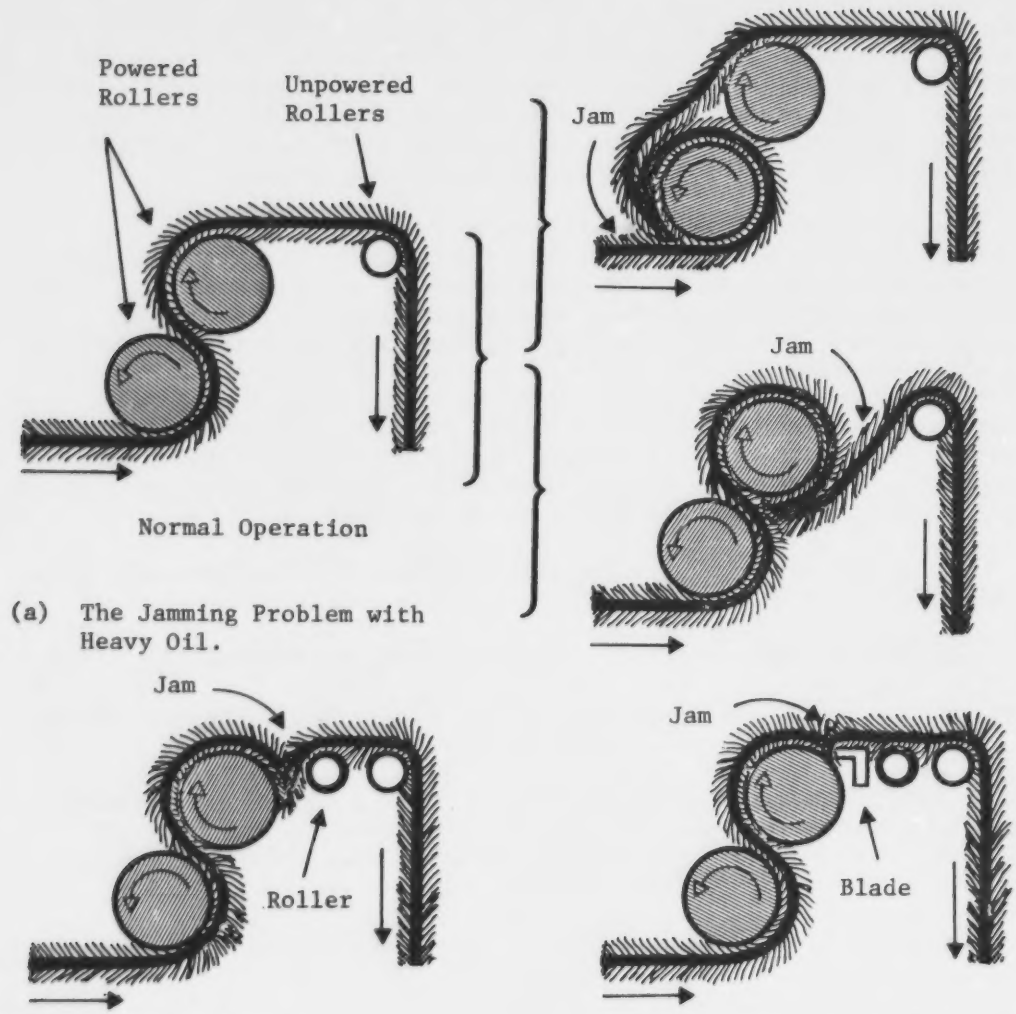
Figure 5. Recovery efficiency trends - Oil Mop Inc. ZRV.

From Figure 4, it can be seen that: (a) TE was consistently better when recovering light oil than when recovering heavy oil, (b) the TE curves fell off gradually as tow speed increased, and (c) the TE curves for light oil in calm water, 0.6 metre harbor chop and 0.8 x 12.4 metre regular waves are all close together. These last two points indicate an insensitivity to wave type and, to a lesser degree, tow speed over the range of 1.0 to 2.5 m/s. Figure 5 shows that the RE performance parameter is also relatively insensitive to tow speed and, to a lesser extent, wave conditions for light oil.

Discussion

Initital checkout tests yielded two important results. First, the maximum wave and tow speed conditions for subsequent oil tests were established at a 3 m/s tow through a 0.8 x 12.4 metre wave train. Pitching motions at this speed were such that, if they occurred during actual spill operations, they would certainly induce the skimmer operator to lower the forward speed to reduce pitching. Therefore, an upper limit on the wave and tow speeds for the oil collection data runs was set at 2.5 m/s through a 0.8 x 12.4 metre wave train. Second, during checkout runs with heavy oil at 1 m/s, the 25 cm diameter mops jammed in the bow wringer assembly. Since this condition did not exist at tow speeds of 3 m/s with no oil or with light oil present, it was concluded that heavy oil was causing the individual strands of polypropylene mop to adhere to the wringer rollers, causing a jamming section either forward or aft of the bottom powered roller. A second nonpowered roller and a doctor blade comprised of angle iron placed close to the top power roller were added, but neither solved the jamming problem. It was then decided to conduct the first oil performance runs using light oil and the 25 cm diameter mops, which did not jam, and later install smaller 15 cm diameter mops for the heavy oil tests.

Even with installation of the smaller 15 cm diameter mops for the heavy oil tests, no data was obtained above 1.5 m/s due to the continued wringer jamming problem illustrated in Figure 6.



(a) The Jamming Problem with Heavy Oil.

(b) Addition of Second Unpowered Roller

(c) Addition of Angle Iron Doctor Blade

Figure 6. Oil Mop Inc. ZRV jamming conditions.

The majority of the tests were conducted with light oil. Adjustments of the relative mop speed were made initially to determine the best setting. Test runs confirmed that a zero relative velocity condition between the rotating mops and the oil slick would yield the best TE value.

The position of the data for heavy oil below 1.0 m/s was due to the spreading of the test slick uniformly across the space between the hulls. As the total width of the six mops did not completely fill up this space, some oil passed between the mops and hulls and down the

center line gap between the two groups of three mops. At speeds above 1 m/s, where the majority of the data were taken, the bow wave formed by the catamaran hulls concentrated the oil slick against the two gangs of three mops so that the mops could encounter a larger percentage of the test oil. In general, it seemed that the performance of the skimmer could be improved by placing the two gangs of three mops closer together along the center line of the inner catamaran hull spacing.

Determination of the RE performance parameter is the most accurate since it is directly measured and is independent of the oil slick encounter percentage. The TE and ORR parameters are very sensitive to an accurate knowledge of the volume of oil encountered by the skimmer during the test. For certain runs, the encounter percertage of the test oil slick was not 100%. In these cases, an estimate of the encounter percentage was made from sequential 35 mm slides taken of the slick entering the skimmer bow during the test run. For some tests of this kind the inaccuracy in the knowledge of percent encounter led to a calculation of a TE value greater than 100%. In these cases, neither TE nor the ORR which depends on the TE value were reported.

During the course of testing the following modifications were made to improve performance:

(1) Set of six non-powered rollers across the drip pan.

(2) Splash shield to capture oil being thrown off the mops as they are pulled up over the stern roller.

Due to time limitations, other modifications required to eliminate the jamming problem with heavy oil above 1.5 m/s could not be performed. After the conclusion of these tests, the bow wringer assembly was redesigned by the manufacturer to prevent mop jams.

A complete set of tabular data is given in Tables 5 and 6.

TABLE 5. TEST RESULTS - OIL MOP ZRV (HEAVY OIL) AVERAGE VISCOSITY: 3000 x $10^{-6}m^2/s$

Test no.	Tow speed m/s	Oil dist. rate $(m^3/s)x10^{-3}$	Slick thick. mm	Waves m x m	Encounter %	Rel. mop speed m/s	Rec. eff. %	Thru eff. %	Oil rec. rate $(m^3/s)x10^{-3}$
11	1.0	4.54	3	0	100	0	76	46	1.6
11A	1.0	5.10	3	0	100	0	74	59	2.4
12	1.0	4.73	3	0	100	0	79	69	2.5
13	1.0	4.91	3	0	100	*	84	69	2.7
13A	1.0	4.73	3	0	100	*	83	65	2.5
13B	1.0	3.78	3	0	100	*	67	49	1.4
13C	1.5	7.12	3	0	100	0	72	57	3.3
13D	1.5	6.80	3	0	100	0	78	70	3.8
15	0.5	2.14	3	0	100	0	85	--	--
15A	0.5	2.01	3	0	100	0	60	78	1.2
15B	0.5	2.14	3	0	100	0	51	65	1.1
15C	0.5	2.39	3	0	100	0	46	71	1.3
19	0.5	2.27	2	0.6HC	50	0	63	--	--
19A	0.5	2.65	3	0.6HC	75	0	41	69	1.1
18B	0.5	2.52	3	0.6HC	65	0	38	78	8.5
19C	0.5	2.02	3	0.6HC	70	0	33	85	0.9
20	0.5	2.08	3	0.6HC	45	0	28	87	0.6

*max w/o slippage

TABLE 6. TEST RESULTS - OIL MOP ZRV (LIGHT OIL) AVERAGE VISCOSITY: $9 \times 10^{-6} m^2/s$

	TEST CONDITIONS					TEST RESULTS			
Test no.	Tow speed m/s	Oil dist. rate $(m^3/s) \times 10^{-3}$	Slick thick. mm	Waves m x m	Encounter %	Rel. mop speed m/s	Rec. eff. %	Thru eff. %	Oil rec. rate $(m^3/s) \times 10^{-3}$
6B	1.0	5.48	3	0	100	0	65	84	3.5
25	1.0	4.34	3	0	100	0	63	62	2.1
25A	1.0	5.10	3	0	95	0	75	90	3.5
25B	1.0	5.23	3	0	100	0	78	78	3.2
26	1.0	5.10	3	0	100	(+0.25)	65	61	2.5
26A	1.0	5.10	3	0	100	(+0.25)	64	52	2.1
27	1.0	5.04	3	0	100	(+0.5)	69	52	2.1
27A	1.0	5.04	3	0	100	(+0.5)	59	58	2.3
27B	1.0	5.54	3	0	100	(+0.5)	59	51	2.2
29	2.0	9.20	3	0	95	0	64	72	5.0
29A	2.0	9.39	3	0	100	0	60	62	4.7
30	2.5	11.66	3	0	100	0	49	49	4.5
30A	2.5	12.22	3	0	100	0	52	44	4.2
28	2.5	11.34	3	0	90	0	44	36	2.9
35	1.0	4.85	3	0.6HC	95	0	50	58	2.1
35B	1.0	4.98	3	0.6HC	95	0	57	86	3.1
35C	1.0	4.98	3	0.6HC	90	0	58	88	3.1
35A	1.0	5.42	3	0.6HC	90	(+0.25)	50	56	2.1
36	2.0	9.45	3	0.6HC	75	0	42	62	3.5
36A	2.0	9.00	3	0.6HC	90	0	48	72	4.6
36B	2.0	9.39	3	0.6HC	95	0	42	52	3.7
38	2.0	9.14	3	0.6HC	75	(+0.25)	37	52	2.8
37	2.5	12.10	3	0.6HC	80	0	36	42	3.3
32	1.0	4.66	3	0.8x12.4	55	0	53	--	--
32A	1.0	4.73	3	0.8x12.4	50	0	69	--	--
33	2.0	8.82	3	0.8x12.4	85	0	40	51	3.0
33A	2.0	9.00	3	0.8x12.4	80	0	49	79	4.5

SECTION 3

CYCLONET 050 SKIMMER

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Oil collection performance tests were conducted with the Cyclonet 050 skimmer during the period 22 August to 2 September 1977. A total of 26 data runs were conducted with high viscosity (heavy) oil and 19 data runs with low viscosity (light) oil.

Best Performance--

The highest average values of the three skimmer performance parameters, TE, RE, and ORR, for each of the heavy and light oil tests are listed along with key test conditions in Tables 7 and 8 below.

TABLE 7. HIGHEST AVERAGE RESULTS - HEAVY OIL TESTS (CYCLONET 050)

Performance parameter	Highest average value	Tow speed m/s	Wave condition ht x length (m x m)
TE	34%	0.75	0
RE	27%	0.75	0.18 x 8
ORR	0.9 (x $10^{-3}m^3/s$)	0.75	0

TABLE 8. HIGHEST AVERAGE RESULTS - LIGHT OIL TESTS (CYCLONET 050)

Performance parameter	Highest average value	Tow speed m/s	Wave condition ht x length (m x m)
TE	20%	0.75	0
RE	12%	1.50	0
ORR	0.6 (x $10^{-3}m^3/s$)	1.50	0

The above values are the highest of the averages of all individual test results calculated for each test tank condition. Although certain test results may be higher than the values listed above, the use of an

average is more representative of the true value since it compensates for unavoidable random experimental errors. For an overall indication of the trends of the three performance parameters, the average values of results are plotted in the Test Results section for each test tank condition used.

Operating Limits--

Two major oil loss mechanisms were consistently observed in both calm water and wave tests, and placed a definite upper limit on performance. These oil loss mechanisms were:

(1) Vortex shedding of oil out the bottom of the convergent side wall near the point of attachment to the hydrocyclone.

(2) Losses underneath the hull of the Zodiac boat at all speeds.

A number of preliminary tests were conducted to quantify the oil losses from each of the above two mechanisms. Based upon these tests, modifications (described in the TESTS RESULTS AND DISCUSSION section) were made before any of the data reported here was collected.

Even with the modifications installed, test data show that the speed range limits of the device in calm water are from 0.75 to 1.5 m/s, with TE values below 10% in a 0.15 m harbor chop wave condition and a tow speed of 0.75 m/s for light oil.

Mechanical Problems--

Mechanical problems encountered in obtaining good test data were due to the required delicate adjustments of the two Cyclonet units with respect to the Zodiac boat. Modifications to the convergent side wall mouth of the skimmer, and pitch and yaw adjustments of the two skimmer units were required to achieve the best test results. These modifications are described in the TEST RESULTS AND DISCUSSION section.

The diesel engine, pump and piping presented no mechanical problems throughout the two week period.

Recommendations

The two weeks of OHMSETT testing provided a comprehensive performance evaluation of the Cyclonet 050. Mechanisms which caused consistent losses were examined. Adjustments were made to the design of the unit under the direction of the manufacturer and the losses minimized. Any further testing of the Cyclonet 050 should be performed under actual field conditions to establish its operational usefulness.

SKIMMER DESCRIPTION

The Cyclonet 050 skimmer consists of two Cyclonet units mounted on either side of an inflatable Zodiac boat. The skimmer was developed by

Alsthom/Atlantique of Grenoble, France. The test version was manufactured under license in the United States. The oil slick enters the front of the device into the convergent area, where it is concentrated, and then the hydrocyclone chamber through the below-water entrance port. Once inside the hydrocyclone chamber, oil and water are separated by centrifugal action induced by the forward way of the device. Oil is concentrated near the top of the chamber and pumped out of the unit to storage while clean water is expelled to the sea through the exit port of the hydrocyclone side wall. Symmetrical Cyclonet units are mounted on either side of the Zodiac boat and connected to a common pump. The pump is a diesel-driven, Spate induced-flow pump. Its maximum pumping rate is approximately $6.3 \times 10^{-3} m^3/s$. The Cyclonet 050 tested had no onboard storage for recovered oil. The manufacturer suggests the use of collapsible pillow tanks placed inside the Zodiac boat. The skimmer operator can adjust the flowrate out of each Cyclonet hydrocyclone by means of valves on the common pump manifold and by adjusting the speed of the pump diesel prime mover. The depth of each Cyclonet can be adjusted by a hand winch. A typical crew consists of two men, the outboard motor operator and skimmer operator.

The skimmer is 5.8 metres long and 4 metres wide, measured between the outboard edge of each skimmer convergent. In normal operation the Zodiac is powered by an outboard motor. For testing purposes, the device was rigged between the towing bridges and towed down the test tank. Figures 7 and 8 show the device under test at OHMSETT and a schematic of its operation. Additional manufacturer specifications are presented in Appendix D.

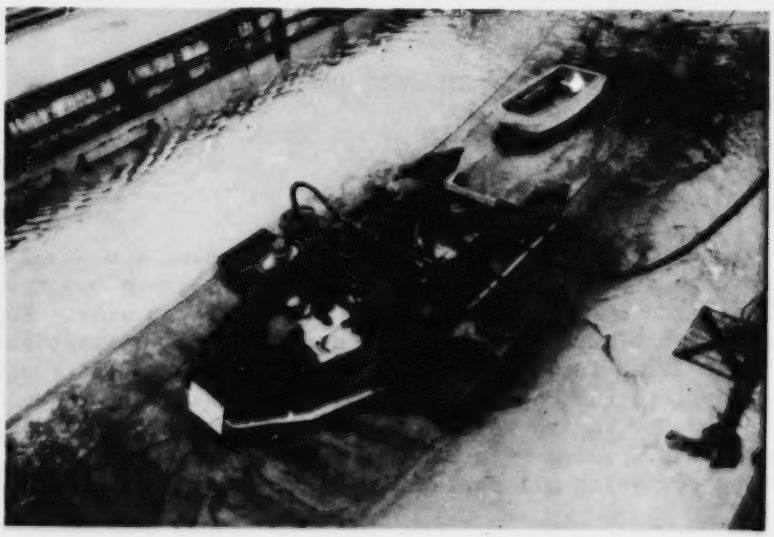


Figure 7. CYCLONET 050 under test.

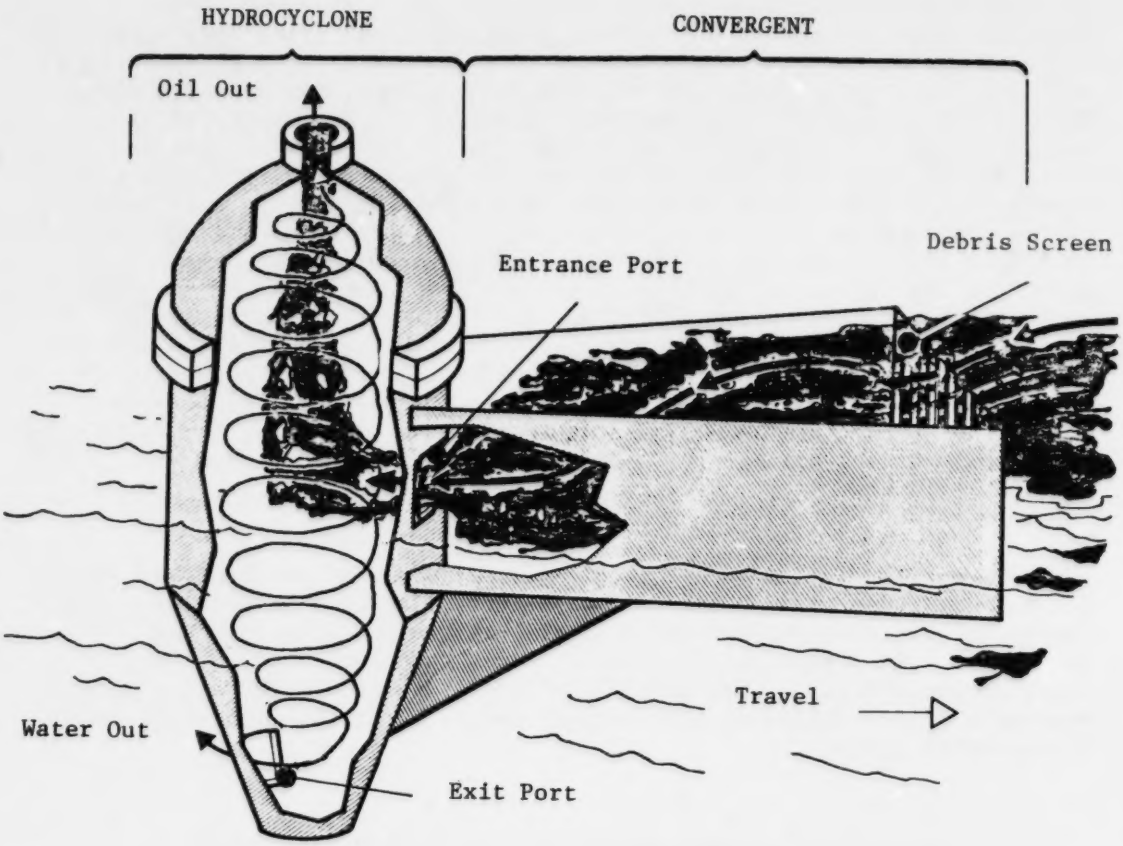


Figure 8. CYCLONET 050 schematic.

TEST MATRIX AND PROCEDURES

Test Matrix

Tests for the Cyclonet 050 skimmer were conducted according to a matrix consisting of shakedown runs, to establish maximum tow speed and wave conditions, and oil data runs with heavy and light oils. Repeated runs were made within the test matrix to examine areas of particular interest. These areas included examining the performance of a single Cyclonet hydrocyclone (as opposed to the complete skimmer system of two hydrocyclones and the Zodiac boat) and performing a series of runs to examine the maximum loading of a single hydrocyclone. Table 9 lists test conditions for which oil collection performance data was obtained.

TABLE 9. TEST MATRIX - CYCLONET 050

Test mode	Tow speed (m/s)	Slick thk. (mm)	Waves (m x m)	Test oil
Slick across both both Cyclonets and Zodiac	0.5	1	0	Heavy
	0.75	1	0	Heavy
	1.0	1	0	Heavy
	1.5	1	0	Heavy
	0.75	1	0.18 x 8	Heavy
	1.5	1	0.18 x 8	Heavy
	0.75	1	0.15 HC	Heavy
	0.75	3	0	Heavy
	1.0	3	0	Heavy
	1.5	3	0	Heavy
Slick into one Cyclonet	0.75	2	0	Heavy
	0.75	1	0	Heavy
Slick across both Cyclonets and Zodiac	0.75	1	0	Light
	1.0	1	0	Light
	1.5	1	0	Light
	0.75	3	0	Light
	1.5	3	0	Light
	0.75	1	0.15 HC	Light
	0.75	1	0.18 x 8	Light
Oil injected directly into one hydro-cyclone	0.75	---	0	Light
	1.5	---	0	Light

Procedures

For all tests the Cyclonet skimmer was towed with a bridle approximately 3 metres behind the main towing bridge at a distance of approximately 7.3 metres from the tank's west wall. The test oil slick was between 3 and 4 metres wide and confined by two floating ropes attached to the outboard edge of each skimmer convergent side wall. Three different size collection barrels, 10.93 m^3, 0.37 m^3, and 0.06 m^3, were stationed on the auxiliary bridge.

Observations were made with 16 mm movie, 35 mm still, and underwater video cameras. The bottom of the Zodiac boat was painted white and the test oils were dyed red to ensure good photographic contrast for oil escaping under the boat.

The final procedures for data collection were established during initial shakedown tests with oil. Oil/water grab samples of the skimmer pump discharge were taken at regular intervals for initial oil runs and were plotted to determine when steady state was being reached. From this information, the final test procedure was established for the oil data test runs.

Following the procedures of Table 10, it was possible to reasonably ensure that the skimmer had reached a steady-state operational level and that all oil collected during this steady-state period had been off loaded into the collection barrels. However, to be certain steady-state recovery efficiencies were being measured, discrete pump discharge samples were continuously taken throughout all runs. A discussion of the oil/water sampling procedures used during the 1977 OITC test series is presented in Appendix B. Appendix C lists test oil properties.

TABLE 10. TEST PROCEDURES - CYCLONET 050

1. Start pump with discharge hose out of collection barrel.
2. Start main towing bridge when wave condition has stabilized. Begin test oil distribution.
3. Start scoreboard clock when oil reaches skimmers, clock is initially set at number of seconds that oil is to be distributed, plus 45 seconds.
4. After clock has elasped 45 seconds, direct skimmer pump discharge into collection barrels and begin collecting grab samples at pump discharge connection.
5. Stop test oil distribution after 300 feet or equivalent preset time.
6. Stop collecting samples and secure hose discharge when scoreboard horn sounds - as clock has counted down to zero.
7. Stop pump - begin tow back.

TEST RESULTS AND DISCUSSION

Test Results

During preliminary shakedown runs, it was quickly established that the upper speed limit of Cyclonet 050 operation is about 1.5 m/s. The convergents of the skimmers began to overflow at a tow speed of 2.0 m/s. Tests with oil showed that the required forced vortex did not form in the hydrocyclone chambers at speeds below 0.5 m/s. Waves selected for oil data runs were the 0.18 metre x 8 metre long regular wave, a wave longer than the Zodiac boat, and the 0.15 metre harbor chop. A 0.3 metre harbor chop was attemped but found to be too severe for the device. It should be remembered that in tank testing, a skimmer is towed into an oncoming wave train. At an actual spill, operation may be possible when more severe waves are present by moving at a different relative heading.

Performance of the device in calm water peaked at TE = 38% at 0.75 m/s and decreased to TE = 25% at 1 m/s and to about 18% at 1.5 m/s. At

0.75 m/s in waves, additional turbulence and shedding of oil around the skimmer were observed. This resulted in a decreased TE value to about 28% with the regular wave and to 17% with the harbor chop.

For light oil tests calm water baseline performance was again established. Best performance was at 0.75 m/s with TE = 22%. Performance decreased to about 14% at 1 m/s and then held steady to 1.5 m/s. Tendency of the lighter oil to become mixed in the water column is the primary reason that performance with light oil was reduced over that with heavy oil.

To determine the maximum TE obtainable with the Cyclonet concept (without Zodiac), the oil loss effect of the Zodiac was eliminated by directing a single oil slick into the convergent mouth of one Cyclonet unit. The results of this procedure show that the hull of the Zodiac contributed to a decline in overall efficiency. It should be noted that the difference in Throughput Efficiency between the single Cyclonet and the complete Cyclonet-Zodiac assembly becomes less and less as the speed increases. This confirms observations during the test that, as the Zodiac's bow wave increased with speed, relatively more oil was forced to the sides and into the two Cyclonet convergents rather than underneath the boat. Figures 9, 10, and 11 depict the Cyclonet 050's performance trends graphically. Figures 12 and 13 follow to identify the underside portion of the device and observed losses under tow.

The results shown in Tables 11 and 12 contain data from 45 data runs out of a total of 74 test runs (48 with heavy oil and 26 with light oil). The remaining runs were rejected because modifications to maximize performance were not complete, correct procedures were not followed, or the results were not repeatable.

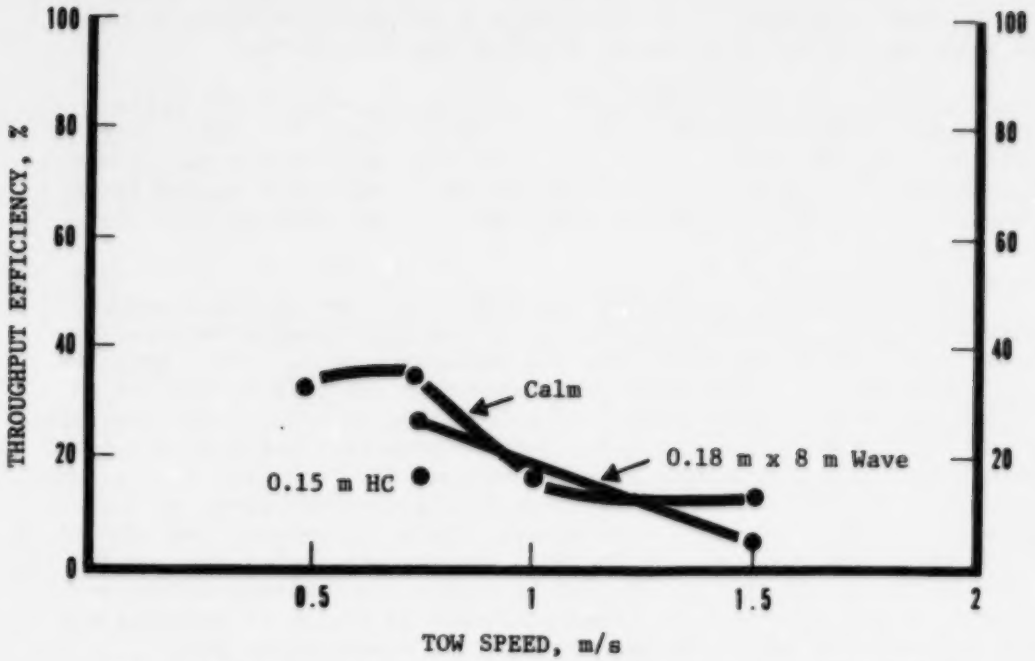


Figure 9. Throughput efficiency (heavy oil) - CYCLONET 050.

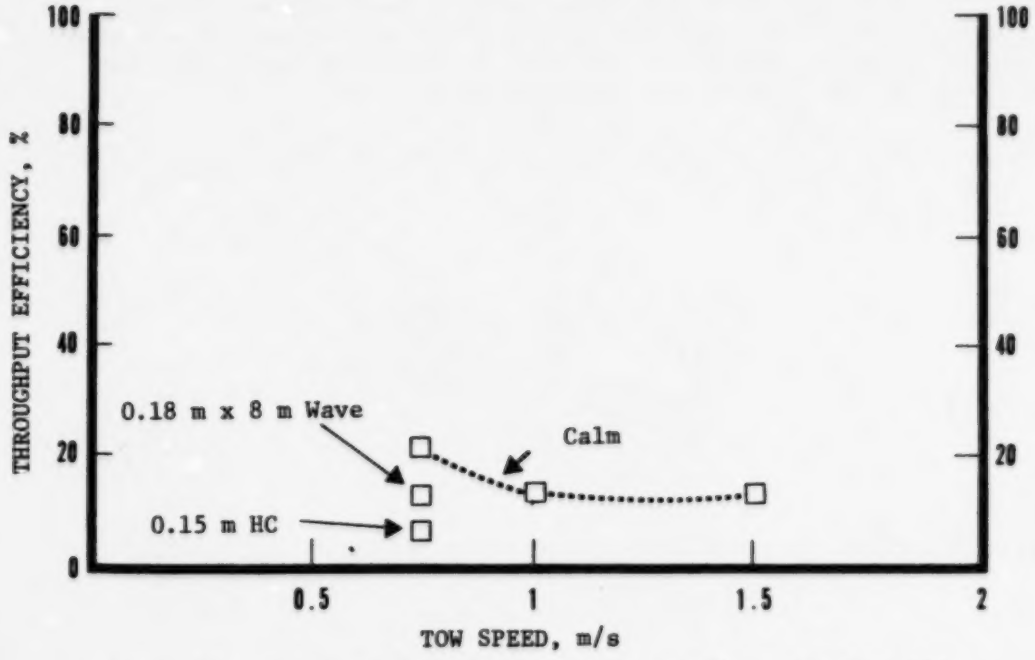


Figure 10. Throughput efficiency (light oil) - CYCLONET 050.

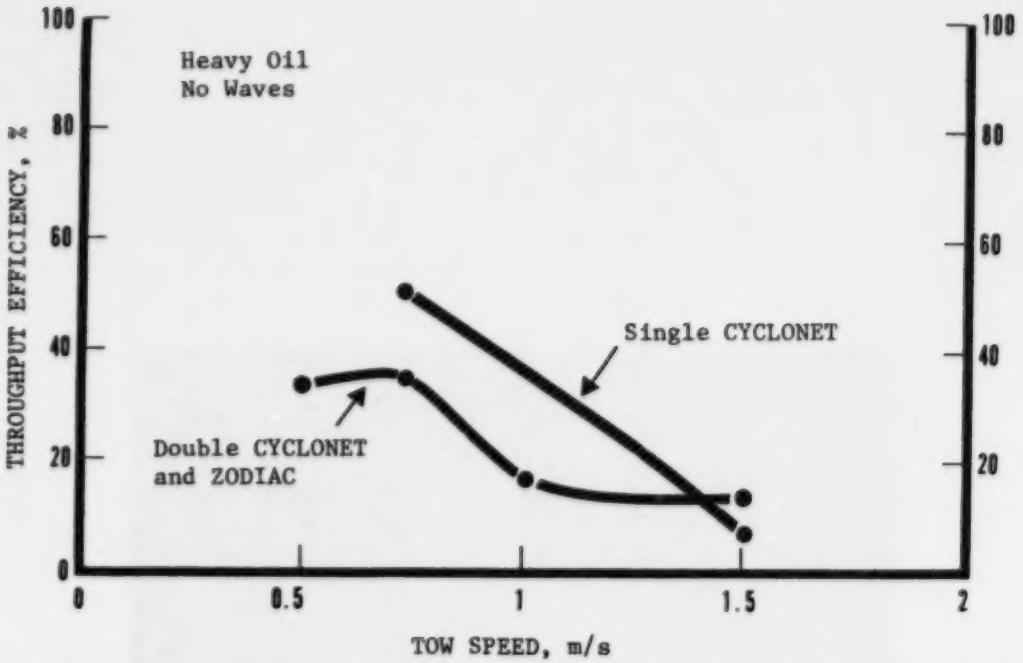


Figure 11. Throughput efficiency - single vs. double CYCLONET 050.

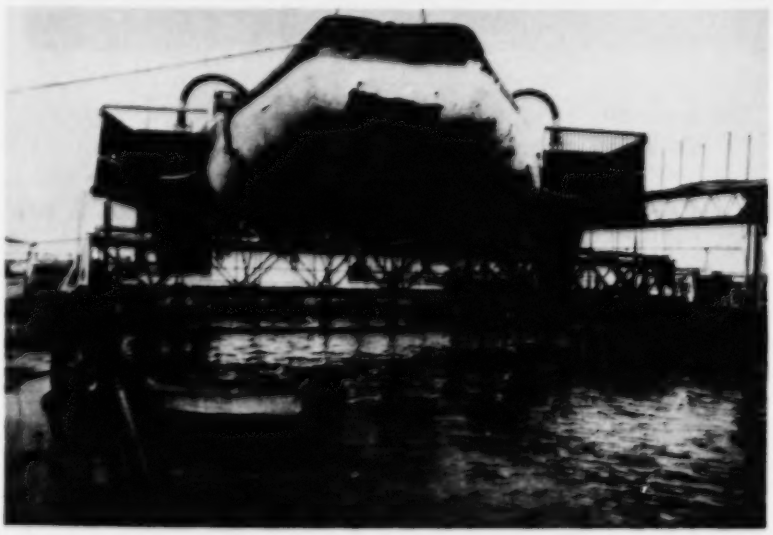


Figure 12. Bow underview - CYCLONET 050 and Zodiac.

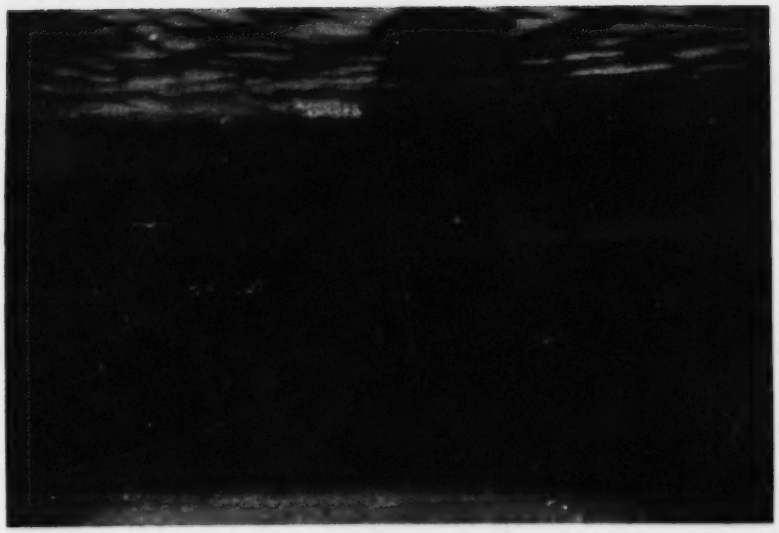


Figure 13. Underwater view - CYCLONET 050 (No waves, 0.75 m/s tow).

TABLE 11. TEST RESULTS - CYCLONET 050 (HEAVY OIL) AVERAGE VISCOSITY: 550 x $10^{-6}m^2/s$

TEST CONDITIONS							TEST RESULTS		
Test no.	Tow speed m/s	Oil dist. rate $(m^3/s)x10^{-3}$	Slick thick. mm	Waves m x m	Encounter %	Pumping rate $m^3/sx10^{-3}$	Rec. eff. %	Thru eff. %	Oil rec. rate $(m^3/s)x10^{-3}$
20	0.5	2.4	1.6	0	100	3.4	22	32	0.8
20A	0.5	1.8	1.2	0	100	3.6	17	34	0.6
16	0.75	2.5	1.0	0	95	3.7	20	31	0.8
19	0.75	2.8	1.2	0	100	3.9	18	25	0.7
19A	0.75	2.5	1.0	0	100	3.6	25	36	0.9
26	0.75	2.8	1.1	0	95	4.6	25	43	1.2
18	1.0	3.1	1.0	0	95	3.6	17	21	0.6
18B	1.0	3.5	1.1	0	100	3.7	8	8	0.3
18C	1.0	3.0	0.9	0	100	3.7	19	23	0.7
21	1.5	4.4	1.0	0	98	3.8	16	14	0.6
21A	1.5	4.8	1.0	0	100	3.7	28	21	1.0
22	0.75	2.8	1.2	0.18x8	95	1.9	42	30	0.8
22A	0.75	2.5	1.1	0.18x8	95	4.0	13	21	0.5
23	1.5	4.5	1.0	0.18x8	100	2.8	8	2	0.3
23A	1.5	4.4	0.9	0.18x8	100	3.0	10	7	0.3
28	0.75	2.8	1.2	0.15HC	95	4.7	7	13	0.4
28A	0.75	2.6	1.1	0.15HC	98	4.6	9	16	0.4
15R	0.75	6.6	2.9	0	90	3.6	50	30	2.0
25	1.0	9.5	3.1	0	90	5.2	14	9	0.8
24	1.5	12.8	2.8	0	95	5.3	19	9	1.1
29	0.75	1.1	*	0	98	3.6	7	24	3.0
30	0.75	1.4	*	0	98	3.6	15	40	0.6
32	0.75	.4	*	0	100	3.6	6	50	0.2
32A	0.75	.8	*	0	98	3.6	15	70	0.6
31	1.5	1.0	.8	0	100	3.1	2	6	0.1
31A	1.5	1.3	1.2	0	100	3.4	3	7	0.1

*Single slick only

TABLE 12. TEST RESULTS - CYCLONET 050 (LIGHT OIL) AVERAGE VISCOSITY: $22 \times 10^{-6} m^2/s$

TEST CONDITIONS							TEST RESULTS		
Test no.	Tow speed m/s	Oil dist. rate $(m^3/s) \times 10^{-3}$	Slick thick. mm	Waves m x m	Encounter %	Pumping rate $m^3/s \times 10^{-3}$	Rec. eff. %	Thru eff. %	Oil rec. rate $(m^3/s) \times 10^{-3}$
33	0.75	2.9	1.3	0	90	4.9	10	19	0.6
33A	0.75	2.8	1.2	0	90	4.6	12	22	0.6
34	1.0	3.1	1.0	0	95	4.7	7	11	0.4
34A	1.0	3.4	1.1	0	98	4.7	9	13	0.4
35	1.5	5.2	1.1	0	98	4.7	12	11	0.6
35A	1.5	5.0	1.1	0	95	4.8	13	13	0.6
36	0.75	7.3	3.1	0	85	5.1	13	11	0.8
36A	0.75	7.5	3.2	0	90	4.9	14	10	0.8
37	1.5	14.0	3.0	0	90	5.1	10	4	0.6
37A	1.5	15.4	3.3	0	95	5.2	9	3	0.5
40	0.75	2.6	1.1	0.15HC	95	5.0	3	6	0.2
40B	0.75	2.4	1.0	0.15HC	90	4.4	3	6	0.2
41	0.75	2.4	1.0	0.18x8	95	4.4	13	25	0.6
41A	0.75	2.2	1.0	0.18x8	95	4.2	5	10	0.3
43	0.75	1.3	*	0	100	3.1	47	112	1.4
43A	0.75	2.1	*	0	100	3.2	62	97	2.0
43B	0.75	2.3	*	0	100	3.2	66	89	2.1
43C	0.75	3.6	*	0	100	3.2	90	80	2.9
44	1.5	2.3	*	0	100	3.1	57	78	1.8

*oil injected into Cyclonet

Discussion

Several modifications were made to the Cyclonet and Zodiac to improve performance. In initial test runs, underwater video revealed that few losses were observed at the underwater hydrocyclone exit port, indicating that the device was not overloaded with oil. However, significant oil losses were seen coming from under the outboard convergent side walls of the Cyclonet collectors and between the sides of the Zodiac and the inboard convergent walls. Most serious was the oil loss from a vortex in the convergent area just forward of the hydrocyclone entrance port. To reduce the oil losses from these various causes, certain modifications were performed:

(1) To reduce vortex shedding with the convergent area a triangular portion on the convergent was removed.

(2) To prevent losses between the boat and the convergent and to smooth the flow into the convergent entrance, the convergent was pulled against the side of the Zodiac with a cable jack.

(3) To reduce convergent oil losses, weight was moved aft to raise the relative pitch of the Cyclonet 5 degrees.

(4) To decrease oil shedding and improve concentration of oil inside the convergent, the debris screens were removed.

Performance improved signficantly after the above modifications were made, although oil losses by vortex shedding in the convergent area were still observed and the performance of the device was still sensitive to other skimmer adjustments of height and yaw angle of the tow. The modifications as mentioned are detailed in Figure 14.

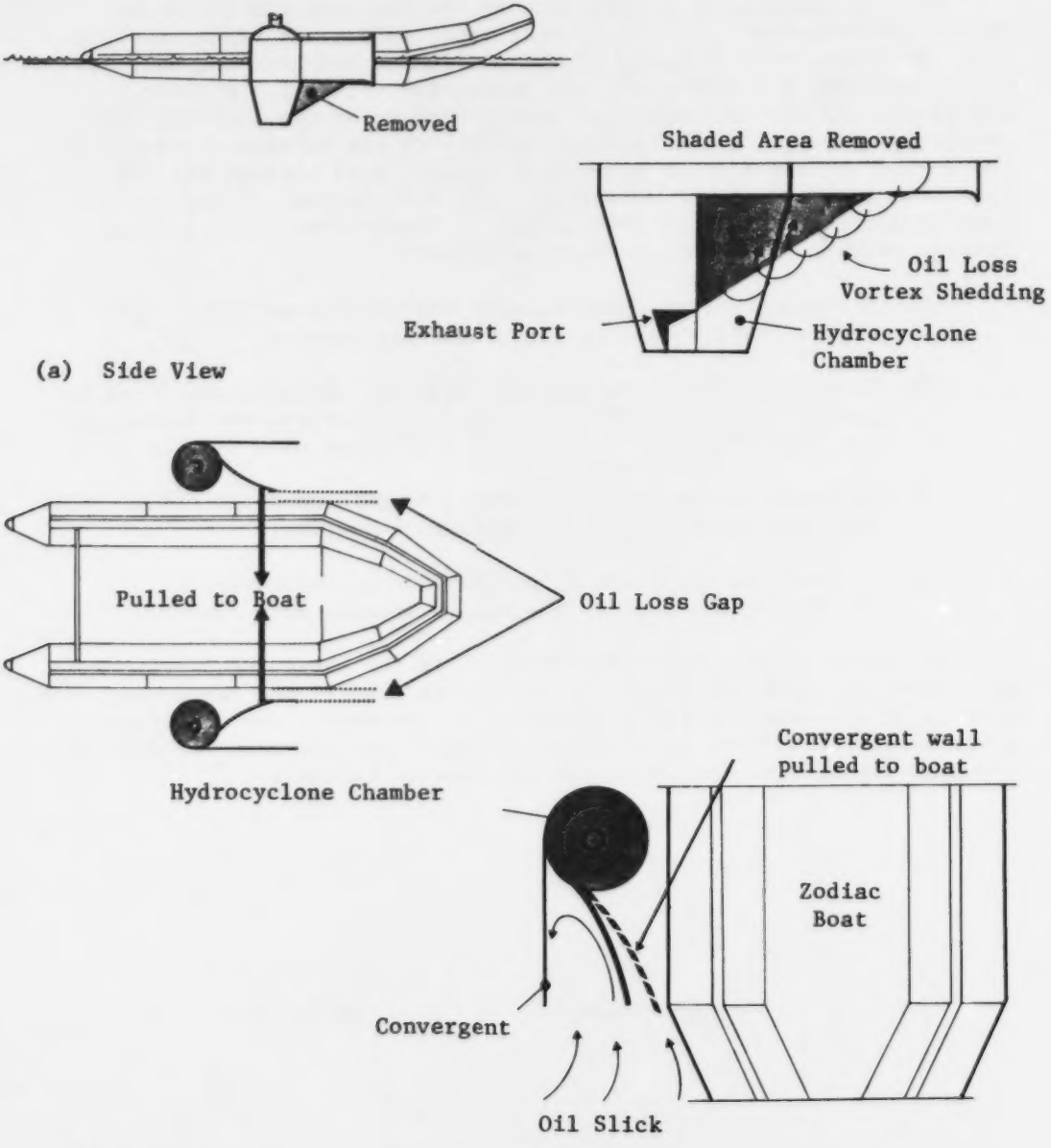


Figure 14. Modifications to CYCLONET 050

A final effort was made to establish the upper limits of the Cyclonet hydrocyclone concept excluding all the oil loss mechanisms listed above, which are unique to the Cyclonet-Zodiac combination. This was accomplished by directing the test oil distribution hose to discharge directly into the Cyclonet hydrocyclone entrance port, thus completely bypassing the Zodiac boat and convergent. The results of this direct injection procedure indicate a Recovery Efficiency of 54% for a corresponding Throughput Efficiency of 100%. For a constant tow speed, as the oil distribution rate increases, the Recovery Efficiency increases, but at the expense of Throughput Efficiency due to the hydrocyclone becoming overloaded. A single data run at a higher tow speed of 1.5 m/s was conducted as a spot check for sensitivity of this behavior to speed. The results of this effort are represented in Figure 15.

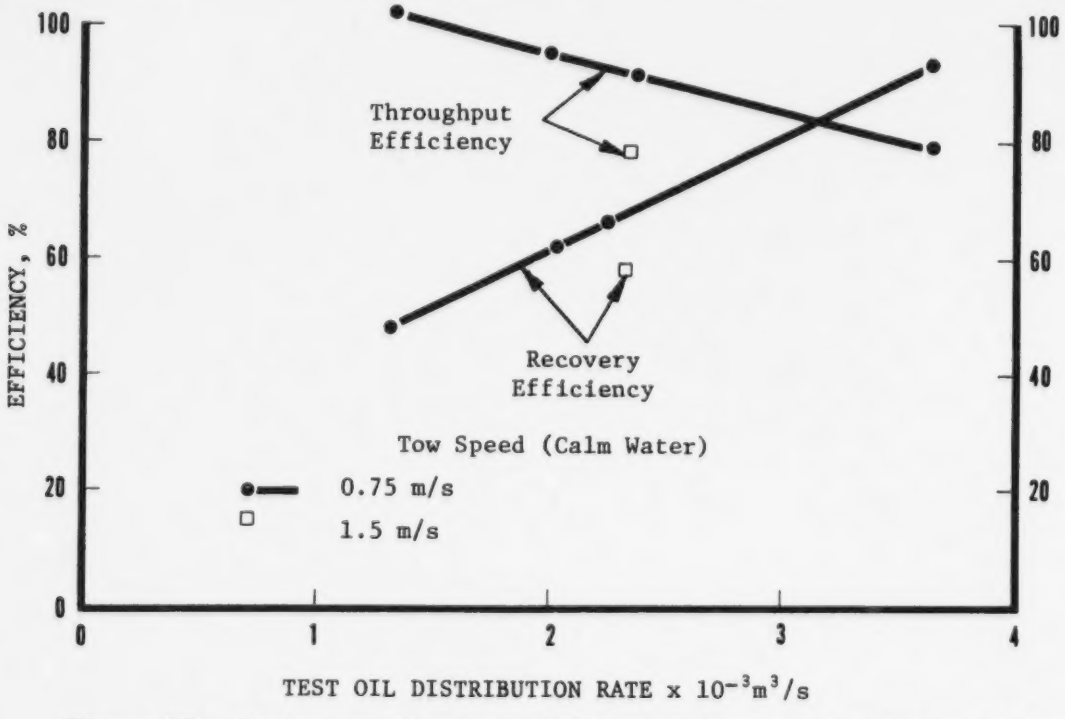


Figure 15. Maximum performance limits with direct injection of light oil into chamber - CYCLONET 050.

It can be concluded from this test series that, for maximum Throughput Efficiency with light oil, the Recovery Efficiency will be about 50% and that the majority of oil is lost from under the Zodiac and in the convergent before the oil gets a chance to enter the entrance port to the hydrocyclone chamber.

Throughout the two week test period, no mechanical problems were encountered with the pump, the diesel engine, or valves and fittings. The device was ready for skimming once the diesel was primed and started. The Zodiac boat lost air pressure and took on water overnight. Wooden

floor boards were very slippery and required matting for safety.

As a result of the performance data obtained in these tests, the manufacturer is now offering a removable deep draft bow section for the Zodiac to prevent oil losses under the shallow draft unmodified Zodiac. This addition also serves to direct more oil into the Cyclonet convergents on either side of the Zodiac.

SECTION 4

CLOWSOR SKIMMER

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

During the period 6 to 16 September 1977, 32 oil collection performance data tests were conducted with the Clowsor skimmer. A total of 21 of these tests were conducted with high viscosity (heavy) oil and 11 tests conducted with low viscosity (light) oil.

Best Performance--

The highest average values of the 3 performance parameters TE, RE, and ORR for each of the heavy and light oil tests are listed in the tables below.

TABLE 13. HIGHEST AVERAGE RESULTS - CLOWSOR (HEAVY OIL)

Performance parameter	Highest average value	Tow speed m/s	Wave condition ht x length (m x m)
TE	96%	0	0
RE	91%	0	0
ORR	6.0 (x $10^{-3}m^3/s$)	0	0

TABLE 14. HIGHEST AVERAGE RESULTS - CLOWSOR (LIGHT OIL)

Performance parameter	Highest value value	Tow speed m/s	Wave condition ht x length (m x m)
TE	61%	0.37	0
RE	65%	0	0
ORR	3.4 (x $10^{-3}m^3/s$)	0	0

The above values are the highest of the averages of all individual test results for each test tank condition.

Operating Limits--

Depending upon slick thickness, the Clowsor showed itself capable

of achieving very high Oil Recovery Rates. The highest rate recorded during these tests was with heavy oil in which the slick thickness reached a maximum of approximately 300 mm during the test and the Oil Recovery Rate reached a maximum value of 6.4×10^{-3} cubic metres per second. An oil recovery rate in excess of this value could have been attained had the supplied pumps been able to off load the skimmer at a higher flowrate.

There are 4 factors which limit the performance of the Clowsor skimmer:

(1) Currents in excess of 0.25 m/s.

(2) Waves in excess of 0.3 metre harbor chop.

(3) Paddle speeds greater than 2.5 rpm.

(4) Oil with viscosity less than about $20 \times 10^{-6} m^2/s$.

Recommendations

The Clowsor skimmer as tested at OHMSETT performed according to its design goals as a high volume oil skimmer for high viscosity oil spills under low wave and low current conditions. The concept of a paddle and perforated ramp combination has been well executed in construction of this skimmer. The range of applicability of the skimmer has been determined during these tests as described in the Operating Limits paragraph above. It is recommended that any further performance tests be conducted during actual spills.

SKIMMER DESCRIPTION

The Clowsor skimmer, manufactured by Anti Pollution, Inc., of Morgan City, Louisiana, is designed as a stationary skimmer operating in calm water and low currents. The Clowsor paddle-perforated ramp concept is available in a number of different sizes for use in shallow or deeper water. The physical dimensions and weights of the manned skimmer tested are listed in Appendix D.

In operation, the oil slick is pulled up a perforated inclined ramp by 4 rotating paddles. As a wedge of oil and water is drawn over the perforated inclined ramp, any water present in the wedge settles downward and passes through the holes in the plate, leaving an oil-rich mixture behind. The paddle pulls the oil-rich fluid wedge up over the top of the incline and into a sump where it is pumped off the skimmer. For these tests, large pumps located on the auxiliary bridge behind the skimmer were used to offload collected oil. In field operation, onboard pumps or shore based vacuum tanks are used to empty the sump. Water settling downward through the holes in the ramp exits from the skimmer through flapper check valves in the bottom of the unit. These valves also prevent surging of water upward through the perforated ramp.

An additional feature of the skimmer is the use of an air floatation oil boom and hydraulic motor recovery reel mounted on the starboard side of the skimmer. This boom is deployed around an oil slick and is secured to the opposite side of the skimmer. Powered retrieval is provided by the hydraulic motor mounted atop the boom recovery reel. When the boom is then reeled in, the contained area in front of the skimmer decreases in area, greatly increasing the oil slick thickness and allowing the paddles to recover more oil and less water.

The skimmer is outfitted with double-pinned standoff struts. These struts allow the skimmer to respond to waves when attached to the bow of a larger vessel such as a barge or small tugboat. During these tests, the struts were bolted to the auxiliary bridge extending across the tank. The Clowsor is shown undergoing a stationary test in Figure 16 and its operating principle is diagrammed schematically in Figure 17.

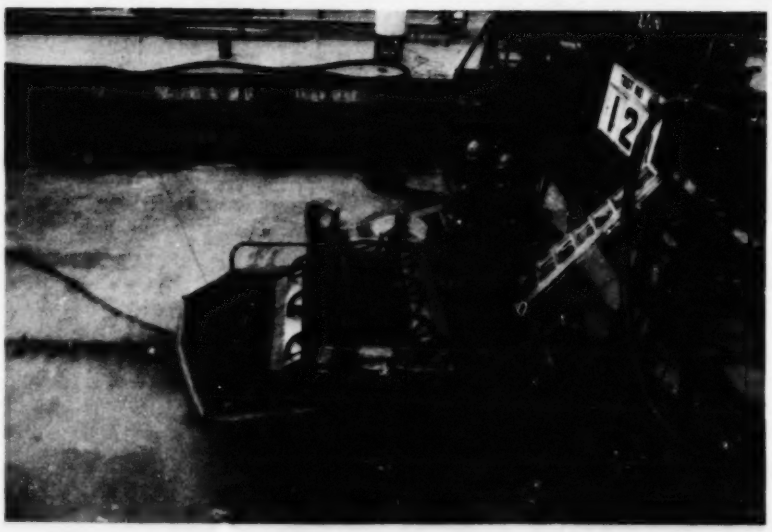


Figure 16. CLOWSOR under stationary test.

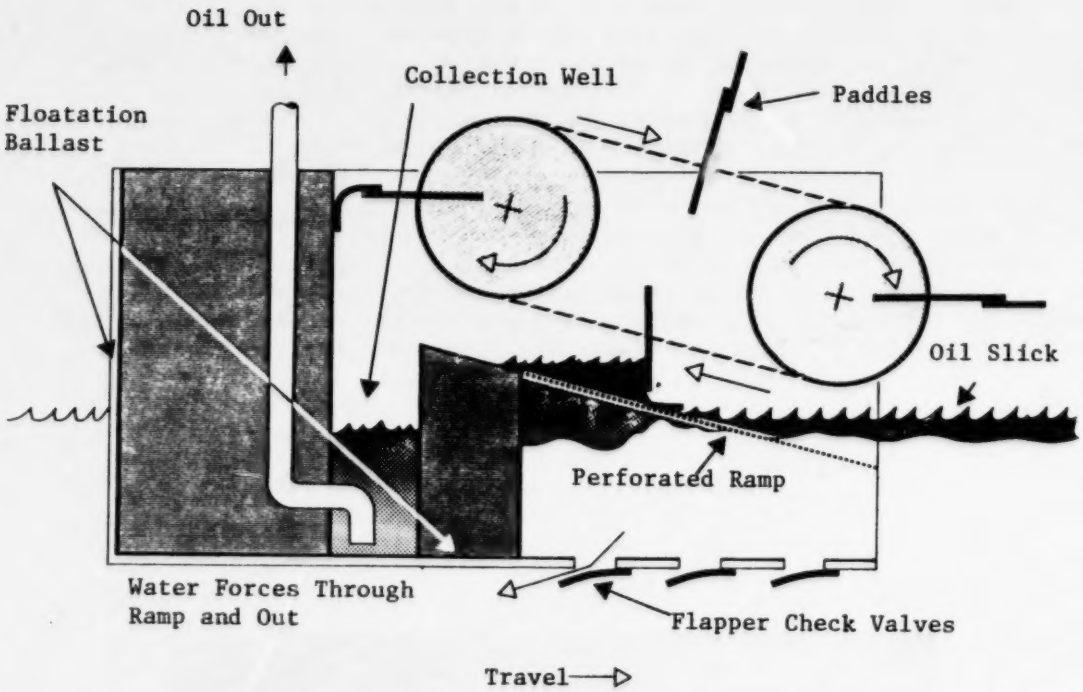


Figure 17. Clowsor Schematic.

TEST MATRIX AND PROCEDURES

Test Matrix

The Clowsor skimmer was tested in the following three modes of operation:

(1) Encircling boom mode.

(2) Stationary mode in thick oil slicks.

(3) Towed mode to simulate currents.

A matrix of the conditions for tests of each of these three configurations is presented in Table 15.

TABLE 15. TEST MATRIX - CLOWSOR

Test mode	Tow speed (m/s)	Slick thk. (mm)	Waves (m x m)	Test oil
Encircling boom	0	51	0	Heavy
Stationary	0	13	0	Heavy
	0	26	0	Heavy
	0	26	0.2 x 8	Heavy
	0	26	0.3 HC	Heavy
	0	0-51	0	Heavy
	0	0-300	0	Heavy
	0	0-22	0	Heavy
	0	0-37	0	Heavy
Towed	0.25	4	0	Heavy
	0.37	4	0	Heavy
	0.25	4	0.3 HC	Heavy
Stationary	0	0-22	0	Light
	0	0-51	0	Light
	0	0-341	0	Light
	0	0-275	0	Light
Towed	0.25	4	0	Light
	0.37	4	0	Light
	0.25	4	0.3 HC	Light

Procedures

The procedures for each of the three test configurations are outlined in Tables 16 through 18. During the latter two series of tests, two difficulties were encountered in collecting repeatable data. First, the two large centrifugal pumps located behind and above the skimmer on the auxiliary bridge tended to lose prime. Second, during some of the high volume flow stationary tests, the oil distribution hose outlet was under the water surface, causing water to become entrained with the rising oil as it surfaced to form the test slick. A splash plate was added to ensure distribution of oil above the water line, and all subsequent tests were performed with this technique. Comparing results of test runs under similar conditions showed that not using a splash plate caused an additional water content of about 10% to appear in the oil presented to the skimmer which the skimmer was not able to separate. Appendix B gives sampling procedures, and Appendix C lists test oil properties.

TABLE 16. TEST PROCEDURES - CLOWSOR (ENCIRCLING BOOM)

1. Pump skimmer collection well dry.

2. Deposit test oil within the encircling boom area in front of the skimmer and activate the skimmer paddles, off loading pump and a stopwatch.

3. Obtain grab samples from the pump discharge at varying time intervals during the run.

4. When the Clowsor operator signals that all the oil has been drawn up the ramp into the sump, continue to run the pump until all liquid is pumped out of the sump and secure the stopwatch.

5. Fill the skimmer sump with water from a fire hose and activate the pump and stopwatch until water appears at the end of the discharge hose at the collection barrel, then take the hose out of the barrel, and secure the pump and stopwatch. From the stopwatch, record the total time the pump was on during the test.

TABLE 17. TEST PROCEDURES - CLOWSOR (STATIONARY)

1. Fill skimmer collection sump with water and activate pumps to establish prime in the pump suction hoses.

2. Activate distribution of test oil into the boomed area in front of the skimmer. At the same time, activate the skimmer paddles, off loading pumps, and stopwatch.

3. During the run, upon signal from the Clowsor operator, adjust the pump discharge valves to maintain a nearly constant level in the skimmer sump to avoid gross changes in skimmer draft.

4. During the run, obtain grab samples from the pump discharge.

5. After a predetermined time interval, usually five minutes, stop test oil distribution. Continue operating the skimmer paddles until the Clowsor operator signals that all oil has been collected. Continue to operate pumps until the skimmer sump is almost dry and then secure pumps, fill the sump with water from a fire hose, and continue pumping into the collection barrels until clear water is observed coming out the end of the discharge hose. Secure the pumps and stopwatch and record the total pump activation time.

TABLE 18. TEST PROCEDURES - CLOWSOR (TOWED)

1. With the skimmer sump filled with water to the proper ballast level, start the tow down the tank and, at a predetermined point, activate test oil distribution.

2. When the test oil slick contacts the front of the paddles, activate the paddles, off loading pumps and stopwatch.

3. Using the choking valves on the discharge side of the off loading pumps, continually adjust the flow rate as directed by the Clowsor operator to maintain a nearly constant ballast level in the skimmer collection sump.

4. Througout the run, obtain grab samples from the pump discharge.

5. At a predetermined point along the tank wall, secure test oil distribution and, at the discretion of the Clowsor operator, secure the paddles before the end of the tow. Continue operating the off loading pumps until the level of the skimmer sump is almost dry. At this point, fill the skimmer sump with water from a fire hose and continue pumping into the collection barrels until clear water is seen coming out the end of the discharge hose. Secure the pumps, stop timing, and record the total pump activation time.

TEST RESULTS AND DISCUSSION

Test Results

Only three tests were run in the encircling boom mode. It was concluded at the end of these three tests that the boom concept would greatly speed oil slick pickup and further testing would not yield any new information.

In the stationary mode tests, conducted in calm water, Recovery Efficiency for heavy oil was consistently in the 85-95% range over a wide variation of oil distribution rates, while a slight decrease in Recovery Efficiency occurred with light oil for increasing oil distribution rates. Performance with regular and harbor chop wave conditions decreased significantly.

In the third configuration tested, the skimmer was slowly towed to simulate stationary operation in the presence of a light current. The effect of waves on performance diminished Recovery Efficiency. Additionally, performance in calm water at tow speeds greater than 0.25 m/s seemed to be decreasing rapidly, based upon underwater observation of the oil droplet cloud pushed underwater by the rotating paddles.

Discussion

A significant reduction in performance in the presence of waves was

observed. This is due primarily to the action of the large surface area paddles slapping the water in front of the skimmer and breaking up the oil slick into droplets. With a usual rotation speed of 1 revolution every 24 seconds, the speed of each paddle tip is approximately 13 cm/s. Even in calm water with no waves, this top speed caused a rather large oil droplet cloud to form in front of the skimmer. This droplet cloud was eventually recovered by the stationary skimmer as the oil droplets resurfaced inside the boomed area in front of the skimmer. However, under tow and in the presence of waves, this oil droplet cloud moved out of the protective area of the encircling boom in front of the skimmer and was lost. Vortices were formed at the paddle edges and appeared to be a major source of the oil entrainment.

No modifications were necessary to optimize performance of the Clowsor skimmer. Figure 18 shows the device under tow and Figures 19 through 21 graphically depict the performance trends of the Clowsor skimmer. Tables 19 and 20 follow which include tabular data derived from this study.

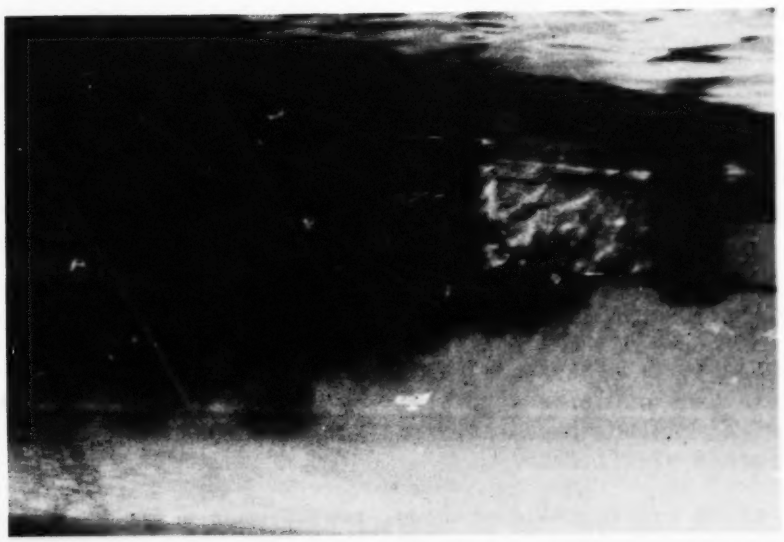


Figure 18. Underwater view - CLOWSOR (no waves, 0.25 m/s tow speed).

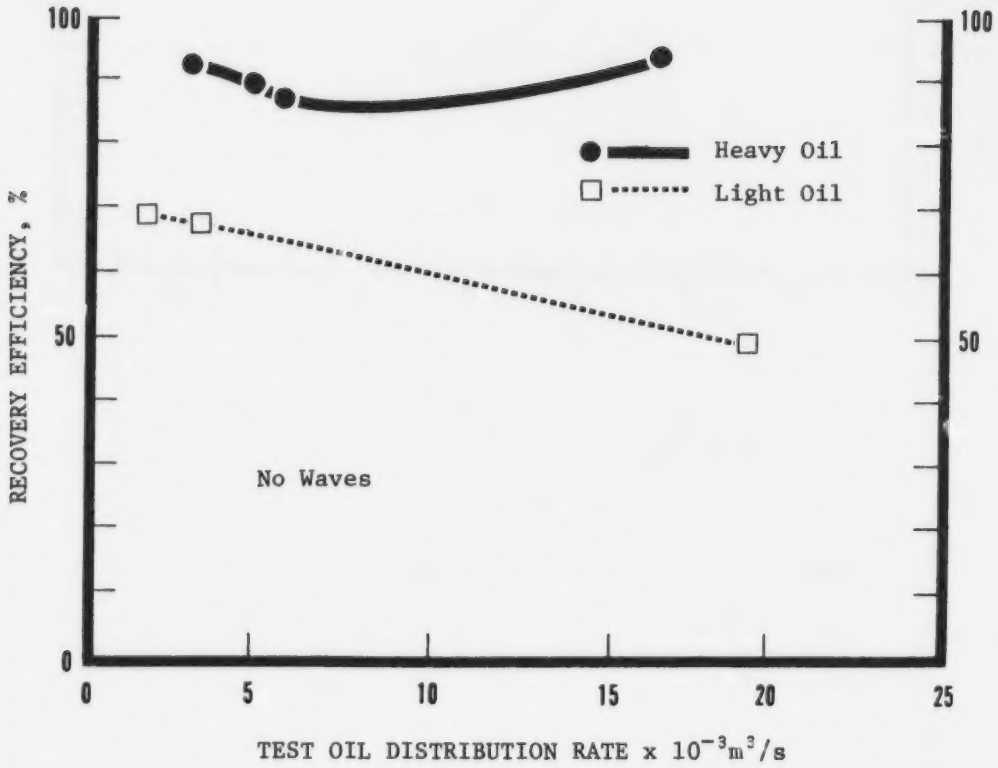


Figure 19. Recovery efficiency trends (stationary tests) - CLOWSOR.

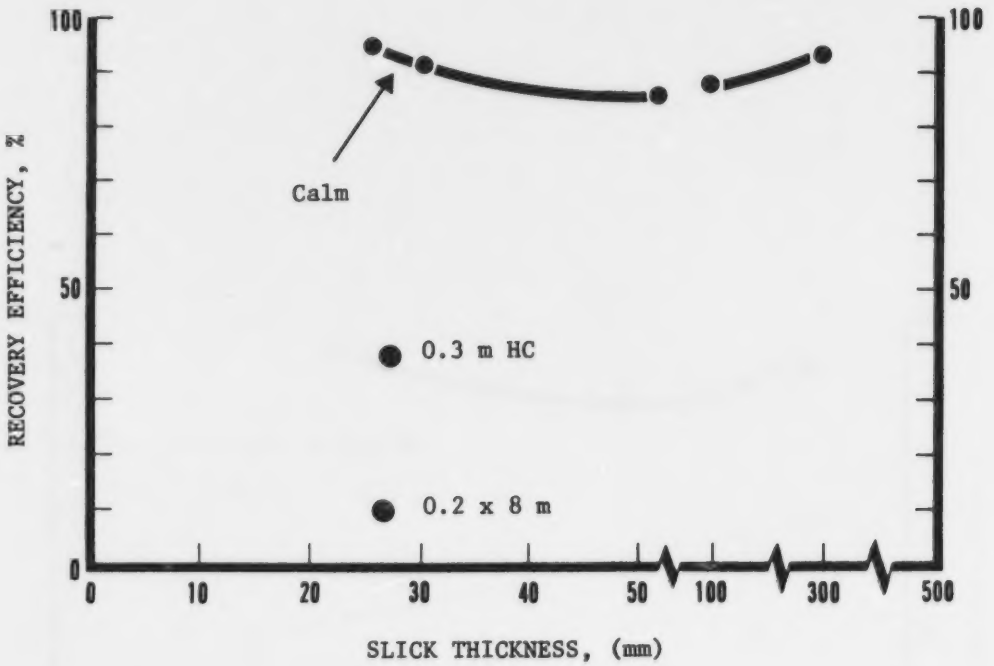


Figure 20. Recovery efficiency trends (stationary tests - heavy oil) - CLOWSOR.

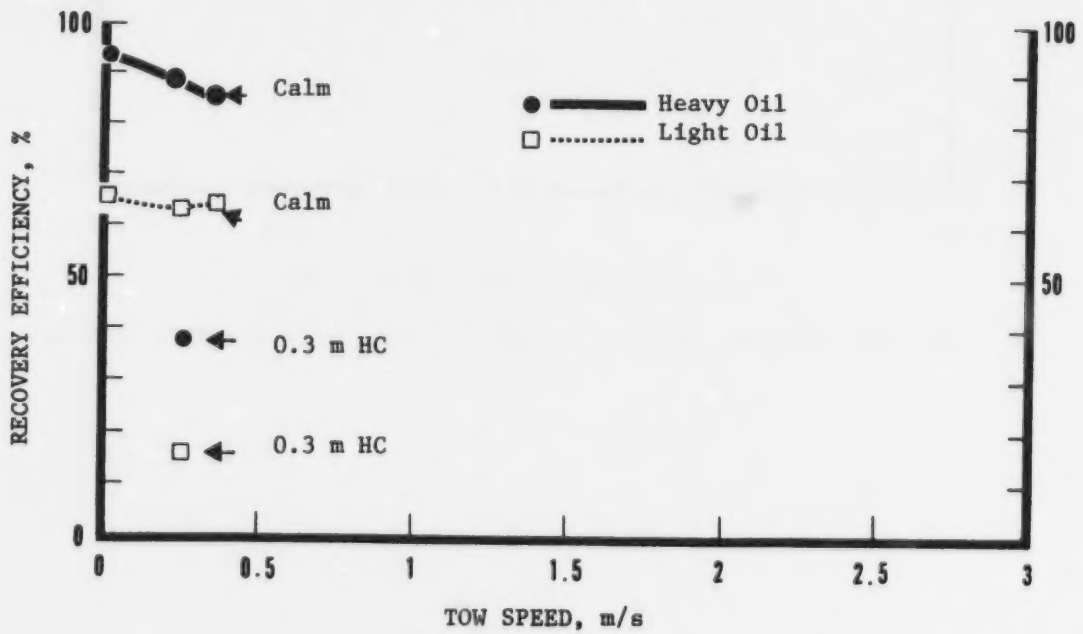


Figure 21. Recovery efficiency trends (towed) - CLOWSOR.

TABLE 19. TEST RESULTS - CLOWSOR (HEAVY OIL) AVERAGE VISCOSITY: 1900 x $10^{-6}m^2/s$

TEST CONDITIONS							TEST RESULTS		
Test no.	Tow speed m/s	Oil dist. rate $(m^3/s)x10^{-3}$	Slick thick. mm	Waves m x m	Total test oil down m^3	Paddle speed rpm	Rec. eff. %	Thru eff. %	Oil rec. rate $(m^3/s)x10^{-3}$
7A	0	0	51	0	0.6	*	87	96	1.8
7B	0	0	51	0	0.6	*	83	96	1.5
7C	0	0	51	0	0.6	*	80	96	1.9
8	0	0	13	0	0.1	*	58	91	0.4
8A	0	0	13	0	0.1	*	82	91	2.1
9	0	0	26	0	0.3	*	78	--	--
9A	0	0	26	0	0.3	*	84	93	2.6
10A	0	0	26	0.2x8.0	0.3	*	7	71	1.4
10B	0	0	26	0.2x8.0	0.3	*	11	72	1.5
11A	0	0	26	0.3HC	0.3	*	35	66	1.1
12	0	5.7	0-51	0	3.5	*	84	97	4.8
13	0	16.4	0-300	0	5.6	*	91	96	6.0
14B	0	1.6	0-22	0	0.5	*	94	66	0.7
14C	0	1.6	ND	0	0.9	*	93	71	ND
15A	0	3.2	0-37	0	0.9	*	94	--	--
15B	0	3.2	0-30	0	0.9	*	89	--	--
17	0.25	3.2	4	0	0.9	2.4	88	85	1.7
17A	0.25	3.2	4	0	0.9	2.5	89	88	1.5
18	0.37	4.7	4	0	0.8	1.4	86	99	3.5
19	0.25	3.2	4	0.3HC	0.9	2.4	40	78	1.7
19A	0.25	3.2	4	0.3HC	0.9	2.4	35	78	ND

*paddle speed varied by operator

TABLE 20. TEST RESULTS - CLOWSOR (LIGHT OIL) AVERAGE VISCOSITY: $14 \times 10^{-6} m^2/s$

TEST CONDITIONS							TEST RESULTS		
Test no.	Tow speed m/s	Oil dist. rate $(m^3/s) \times 10^{-3}$	Slick thick. mm	Waves m x m	Total test oil down m^3	Paddle speed rpm	Rec. eff. %	Thru eff. %	Oil rec. rate $(m^3/s) \times 10^{-3}$
23	0	1.6	ND	0	0.5	2.4	60	63	ND
23A	0	1.6	0-22	0	0.5	3.5	67	81	0.8
24	0	3.2	0-51	0	0.9	2.5	66	36	1.3
24A	0	3.2	0-20	0	0.9	2.5	65	49	2.4
25	0	19.0	0-341	0	4.6	ND	47	50	3.0
25A	0	19.0	0-275	0	3.8	ND	52	74	3.8
20	0.25	3.2	4	0.3HC	0.9	ND	16	41	1.1
20A	0.25	3.2	4	0.3HC	0.9	ND	17	43	1.1
21	0.24	3.2	4	0	0.9	ND	63	67	1.5
21A	0.25	3.2	4	0	0.9	3.5	61	50	0.8
22	0.37	4.7	4	0	0.8	ND	64	65	1.8

SECTION 5

BENNETT MARK 6E SKIMMER

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Best Performance--

During the period 17 to 28 October 1977, a total of 99 data runs were performed with the Bennett Mark 6E skimmer. A total of 62 runs were conducted with heavy oil and 37 runs with light oil. The test results at each set of test conditions were averaged to take into account random testing errors. The highest of these averages for each type of oil is presented in Tables 21 and 22 below. The use of the highest average test results over all test conditions is more representative of the true value because random experimental errors are averaged out.

TABLE 21. HIGHEST AVERAGE RESULTS - BENNETT MARK 6E (HEAVY OIL)

Performance parameter	Highest average value	Tow speed m/s	Wave condition ht, m
TE	95%	1.5	0
RE	88%	0.5	0.3 HC
ORR	6.8 (x $10^{-3}m^3/s$)	1.0	0

TABLE 22. HIGHEST AVERAGE RESULTS - BENNETT MARK 6E (LIGHT OIL)

Performance parameter	Highest average value	Tow speed m/s	Wave condition ht, m
TE	90%	0.75	0
RE	64%	1.25	0
ORR	2.3 (x $10^{-3}m^3/s$)	1.0	0

Operating Limits--

The performance of the Bennett Mark 6E skimmer as determined by Throughput Efficiency appears to be limited by four factors:

(1) Wave-following ability of the bow ramp.

(2) Degree of turbulence inside the skimmer as a function of forward skimmer speed and specific positions of the forward and aft gill doors, and bow ramp depth.

(3) Physical properties of oil.

When operating in waves, the bow ramp must be lowered to remain below the water surface as the skimmer heaves. Tests showed that the wave-following ability of the ramp was affected by wave steepness and attempts to lower the ramp in the 0.3 m harbor chop produced increased turbulence in the area of the collection belt, thus causing more oil droplets into suspension and reduced Throughput Efficiencies.

Sensitivity to oil properties and velocity was observed in the comparison of speeds at which TE on the average dropped to below 50%. With heavy oil, this occurred at a forward speed of 2.75 m/s, while with light oil at about 1.25 m/s. Operational effectiveness is thus determined by the tendency of specific oils to become mixed into the water column, exiting the skimmer via the forward and aft gill doors.

The effectiveness of this device with respect to TE is directly related to the stability of the oil/water interface and is seen to diminish as turbulence increases.

Mechanical Limits--

The performance of the device is directly sensitive to operator controlled skimmer settings of the bow ramp and gill doors. Several test runs were required for each condition to find the right combination of settings. The oil off loading rate was limited due to squeeze belt mechanical problems and the pressure of the squeeze belt was not sufficient to force all the oil from within the collection belt. This overload of the collection belt with excess oil was more pronounced with light oil than with heavy oil. In heavy oil tests, oil was removed from the collection belt primarily by a doctor blade assembly.

Recommendations

The Bennett Mark 6E skimmer is a self-contained, powered skimmer showing good performance for collecting oil in moderate wave conditions. The number of moving parts requires a skilled operator familiar with the device in order to set the interdependent adjustments for best oil pickup performance.

A number of modifications are recommended to improve performance. Two would be particularly helpful. First, the squeeze belt mechanism needs increased pressure against the collection belt to ensure removal of all collected oil. Second, adjustment controls for the underwater bow and gill door settings should be simplified and designed to aid the skimmer operator, and indicators should be provided.

The basic performance limits have been established in this test series. Additional testing should be performed (after the recommended modifications have been made) to establish performance with different oils.

SKIMMER DESCRIPTION

The Mark 6E skimmer, manufactured by Bennett Pollution Controls, Ltd., of Vancouver, Canada, is an inshore, self-propelled skimmer. The hull design, a semi-catamaran type, consists of three sections: two outer catamaran-like hulls attached to either side of a center machinery section. The outer hulls contain the transfer pumps and ballast compartments. The skimmer measures 11.25 m in length overall with a beam of 3.9 m. A helmsman and an oil recovery operator are the two crewmen required for skimmer operation. Additional skimmer specifications are provided in Appendix D. Figures 22 and 23 follow, showing the device under test and a schematic of operation.

Figure 22. BENNETT MARK 6E under test.

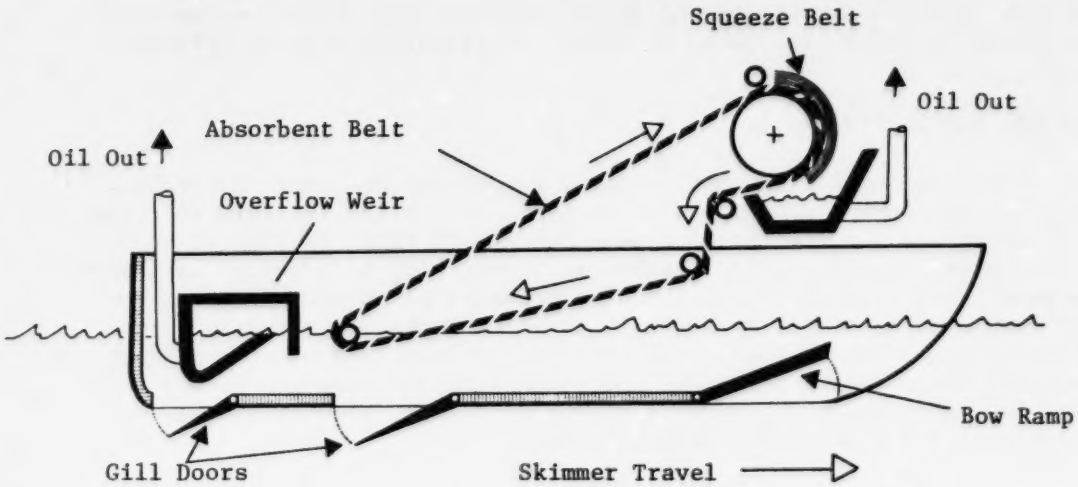


Figure 23. BENNETT MARK 6E schematic of oil collection principle.

The device combines three separate processes for oil/water separation. First, the volume and speed of the oil slick entering the skimmer is regulated by a bow ramp and two gill doors in the floor of the skimmer. The thickness of the layer of water which must be processed with the floating oil entering the skimmer is controlled by adjusting the bow ramp. Opening or closing the gill doors controls the rate at which the floating oil slick moves aft to the rotating, absorbent, polyester wool collection belt. Second, the backward facing, inclined collection belt, which is both oleophilic and hydrophobic, absorbs oil off the water surface, and carries it up to a perforated squeeze belt where the oil is squeezed out into a sump. The third process for collecting oil consists of a baffled overflow weir collection box. Any oil which misses the rotating absorbing belt, due to large oil slick thickness or high forward skimmer speed, is forced under the weir box and up into the quiescent area inside. Oil from the weir box is piped into the oil transfer pumps and offloaded along with oil from the squeeze belt sump.

TEST MATRIX AND PROCEDURES

Test Matrix

After preliminary shakedown tests to finalize procedures and establish tow and wave limits, test runs were conducted with the Bennett Mark 6E skimmer with both heavy and light oil in various wave conditions in accordance with the test matrix in Table 23. Initial tests established a calm water performance baseline for heavy oil, followed by tests in waves and finally with a high rate of oil slick loading into the device. Light oil tests were run in the same manner except that high rate oil slick loading runs were not performed.

TABLE 23. TEST MATRIX - BENNET MARK 6E

Tow speed (m/s)	Slick thk. (mm)	Waves (m x m)	Test oil
0.5	3	0	Heavy
1.0	3	0	
1.25	3	0	
1.5	3	0	
1.75	3	0	
2.0	3	0	
2.25	3	0	
2.5	3	0	
2.75	3	0	
3.0	3	0	
0.5	3	0.18 x 8	Heavy
0.75	3	0.18 x 8	
1.0	3	0.18 x 8	
0.5	3	0.3 HC	Heavy
0.75	3	0.3 HC	
1.0	3	0.3 HC	
1.25	3	0.3 HC	Heavy
1.5	3	0.3 HC	
1.75	3	0.3 HC	
0.75	3	0.6 HC	Heavy
1.0	3	0.6 HC	
1.25	3	0.6 HC	
1.5	3	0.6 HC	
1.0	12	0	Heavy
0.5	3	0	Light
0.75	3	0	
1.0	3	0	
1.25	3	0	
0.5	3	0.3 HC	Light
0.75	3	0.3 HC	
1.0	3	0.3 HC	
0.5	3	0.6 HC	Light
0.75	3	0.6 HC	

Procedures

A number of preliminary shakedown runs were necessary to establish testing procedures for this device. The main problem in finalizing procedures was to ensure the presence of a consistent steady-state operating period for the device during the relatively short tow time down the tank.

Once the steady-state behavior of the device was determined by numerous discrete grab samples during checkout tests, a single, continuous bleed sample procedure was implemented. This arrangement worked

particularly well since the Recovery Efficiency of the rotating absorbing belt remained relatively constant for each oil and the positive displacement pump provided a homogenous oil/water sample. As a result, test run turnaround times were reduced since the composite sample from the large collection barrel on the auxiliary bridge was not required.

The device contains a large internal surface area. To achieve data consistency with the relatively small test oil slick volumes used (about 0.3 m^3), it was necessary to keep a constant oil prime within the skimmer. Several priming runs were sufficient to reach a constant state at the start of each day, or after skimmer adjustment. During testing, the oil slick entering the mouth of the skimmer was carried to the absorbing belt by the surface currents due to the skimmer's forward speed through the water. After towing ceased at the end of a test run, a fire hose was used to maintain this surface current to enable the remaining floating oil to reach the rotating belt. The skimmer was not flushed completely with the fire hose; a constant residual volume of oil was allowed to remain on the inside surfaces of the skimmer as a "prime" between each run.

The procedure used for all data runs is listed in Table 24. Appendix B gives sampling procedures, and Appendix C lists test oil properties. In addition to normal test data, the following skimmer adjustments were also recorded:

(1) Bow and gill door settings.

(2) Belt speed.

(3) Belt depth.

TABLE 24. TEST PROCEDURES - BENNET MARK 6E

1. Start skimmer engine and set bow and gill doors as required.

2. Start main towing bridge and oil distribution as required for the towing speed.

3. Start oil collection belt. When oil has reached the belt surface, time belt speed with a stopwatch.

4. Begin pumping out collected oil from the sump and begin taking grab samples. Collect the discharge oil in the collection barrels on the auxiliary bridge.

5. Stop oil distribution rate after 91.4 m, continue towing.

6. Close bow ramp door when the last of the oil slick enters the device. Hose oil back towards the collection belt as the towing bridge slows down.

(Continued)

TABLE 24. (Continued)

7. Continue hosing the captured oil towards the belt until oil is no longer being collected by the belt. Stop stopwatch and secure grab samples.

8. Pump the oil discharge line dry with the onboard pump, mark collected oil volume height on collection barrel.

TEST RESULTS AND DISCUSSION

Test Results

Calm water tests with heavy oil were conducted at speeds of up to 3 m/s. Successful oil collection occurred above 1.5 m/s because of the ability of the bow ramp to take a thin cut just below the oil slick. Once the oil slick was within the skimmer hull, surface velocities were greatly reduced, allowing oil pickup by the rotating collection belt in a low velocity region. The bow waves produced by each catamaran hull helped concentrate the oil down the center line of the skimmer's interior.

In calm water, the device produced an average TE value of 95% at 0.5 m/s with performance diminishing as speed approached 3 m/s. Throughput efficiency in a 0.3 m harbor chop ranged from 89% at 0.5 m/s to 77% at 1.0 m/s. Beyond this, performance dropped to about 42% at 1.75 m/s. With a 0.6 m harbor chop, the TE was about 50% from 0.75 to 1.5 m/s. As can be seen from the differences in TE values between calm and wave conditions, the device is sensitive to waves and is limited by the maximum wave height of approximately 0.6 m.

With light oil and in calm water the TE value averaged 80% at 0.5 m/s and decreased to 46% at 1.25 m/s. Testing was not continued beyond this tow speed, as the trend was clearly established. The 0.3 m and 0.6 m harbor chop wave conditions had parallel trends. Also, the data reveal greater variations of TE with light oil than with heavy. This is due to the fact that light oils emulsify more readily in wave conditions. Overall, lower performance with light oil was observed.

Oil pickup for all tests was conducted with the rotating absorbing belt alone. Recovery Efficiency values are relatively constant over a wide range of conditions. For heavy oil, Recovery Efficiency is about 80% for all speeds and wave conditions, decreasing with increasing speed as more oil becomes emulsified due to turbulence. RE values for light oil are about 60% for all speeds and wave conditions and show the same general downward trend as for heavy oil. Figures 24, 25, and 26 follow to depict, graphically, the above-mentioned results, and Tables 25 and 26 contain those data points derived from selected tests.

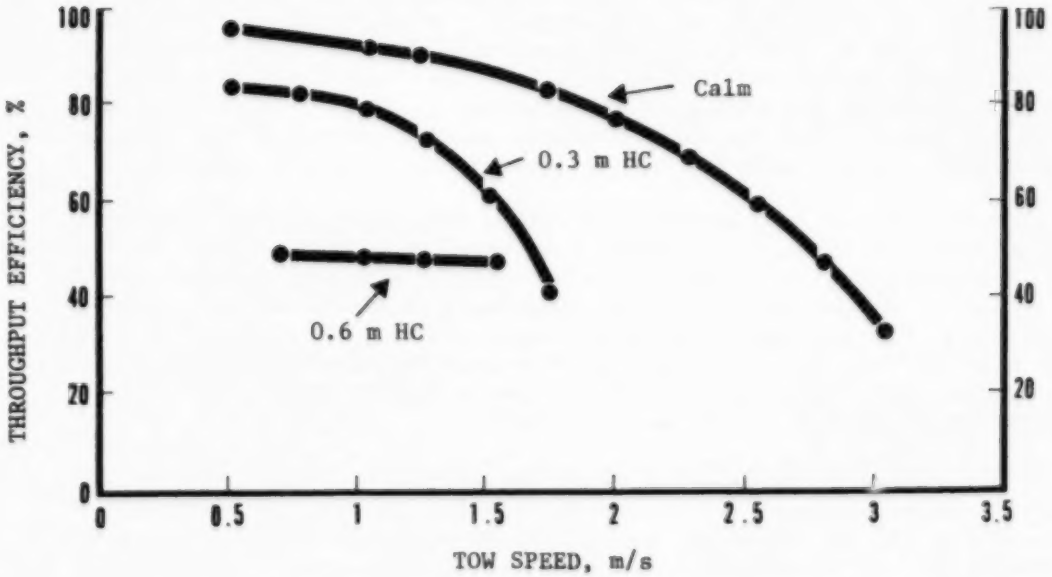


Figure 24. Throughput efficiency trends (heavy oil) - BENNETT MARK 6E.

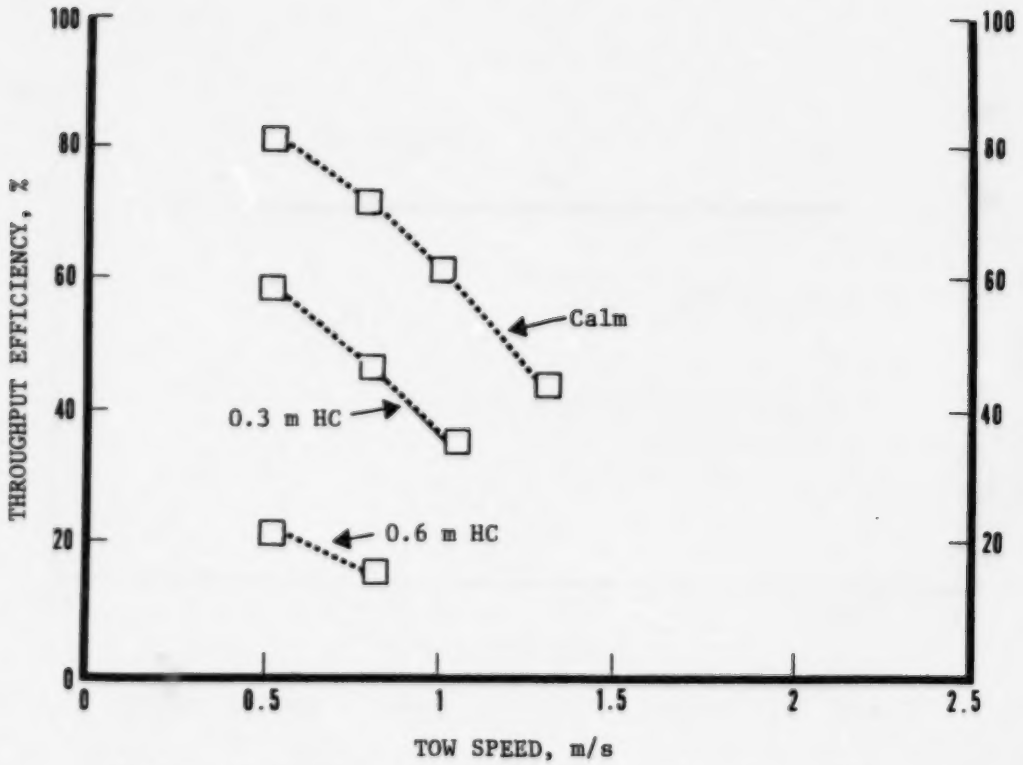


Figure 25. Throughput efficiency trends (light oil) - BENNETT MARK 6E.

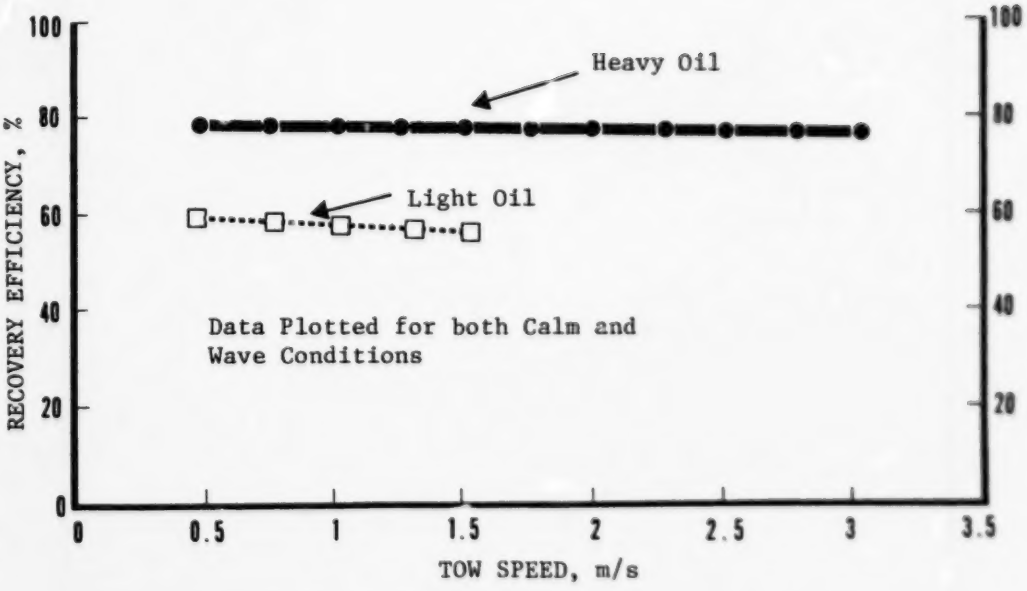


Figure 26. Recovery efficiency trends - BENNETT MARK 6E.

TABLE 25. TEST RESULTS - BENNETT MARK 6E (HEAVY OIL) AVERAGE VISCOSITY: 3000 x 10^{-6} m^2/s

TEST CONDITIONS									TEST RESULTS		
Test no.	Tow speed m/s	Oil dist. rate $(m^3/s)x10^{-3}$	Slick thick. mm	Waves m x m	Enc. %	Door setting Bow	Mid	Aft	Rec. eff. %	Thru eff. %	Oil rec. rate $(m^3/s)x10^{-3}$
7	0.5	1.86	3.0	0	100	1.04	0.47	0.06	83	85	1.6
7A	0.5	1.85	3.0	0	100	1.09	0.50	0.06	86	106	2.0
8	1.0	3.75	3.0	0	100	1.09	0.40	0.06	82	103	3.8
8A	1.0	3.77	3.1	0	100	1.09	ND	0.06	83	73	3.9
8B	1.0	3.86	3.1	0	100	1.09	0.38	0.06	66	73	2.8
9C	1.25	4.67	3.0	0	90	0.99	0.35	0.06	58	78	3.2
10	1.5	5.59	3.0	0	97	0.94	0.16	0.06	86	98	5.2
10A	1.5	5.38	2.9	0	98	0.97	0.24	0.06	74	92	5.7
11	1.75	6.46	3.0	0	98	0.94	0.25	0.06	76	83	5.2
11A	1.75	6.71	3.1	0	100	0.91	0.28	0.06	75	92	6.1
12	2.0	7.16	2.9	0	90	0.86	0.23	0.06	81	81	5.2
12A	2.0	7.58	3.1	0	96	0.81	0.23	0.06	80	65	4.6
13	2.25	8.38	3.0	0	96	0.81	0.30	0.06	76	81	6.4
13A	2.25	8.46	3.0	0	96	0.84	0.28	0.06	75	58	4.6
14A	2.5	10.8	3.3	0	95	0.84	0	0.06	70	59	5.6
14B	2.5	9.0	2.9	0	96	0.84	0.05	0.06	81	66	5.6
15	2.75	10.01	3.0	0	100	0.83	0.05	0.06	80	50	5.0
16	3.0	11.69	3.2	0	100	0.83	0.10	0.06	76	43	5.0
16A	3.0	11.01	3.0	0	100	0.83	0.10	0.06	66	14	1.5
17C	0.5	2.08	3.4	0.18x7.9	98	1.06	0.41	0.06	83	100	2.0
17D	0.5	1.93	3.1	0.18x7.9	100	1.06	0.41	0.06	80	103	2.0
18	1.0	3.85	3.1	0.18x7.9	98	1.06	0.41	0.06	77	34	1.2
18A	1.0	3.56	2.9	0.18x7.9	98	1.06	0.41	0.06	82	39	1.3
18B	1.0	3.65	3.0	0.18x7.9	95	0.99	0.43	0.06	75	30	1.0
18C	1.09	3.27	2.7	0.18x7.9	95	ND	0.30	0.13	80	51	1.6
18D	1.0	3.68	3.0	0.18x7.9	95	0.99	0	0.27	80	55	1.9
18E	1.0	3.61	2.9	0.18x7.9	95	1.17	0	0.27	80	57	1.9

(Continued)

TABLE 25 (Continued)

TEST CONDITIONS									TEST RESULTS		
Test no.	Tow speed m/s	Oil dist. rate $(m^3/s)x10^{-3}$	Slick thick. mm	Waves m x m	Enc. %	Door setting Bow	Mid	Aft	Rec. eff. %	Thru eff. %	Oil rec. rate $(m^3/s)x10^{-3}$
19	0.75	2.83	3.1	0.18x7.9	95	1.06	0	0.27	81	67	1.8
19A	0.75	2.86	3.1	0.18x7.9	95	1.06	0	0.27	82	65	1.7
20A	0.5	1.78	2.9	0.3HC	98	0.99	0.50	0.06	88	89	1.6
20B	0.5	1.88	3.0	0.3HC	98	1.02	0.50	0.06	87	88	1.6
21A	0.75	2.77	3.0	0.3HC	100	1.02	0.50	0.27	84	67	1.9
21B	0.75	2.80	3.0	0.3HC	100	1.02	0.60	0.06	86	59	1.6
21C	0.75	2.80	3.0	0.3HC	100	1.02	0	0.27	86	95	2.6
21D	0.75	2.80	3.0	0.3HC	100	1.02	0	0.27	84	75	2.1
22	1.0	3.60	2.9	0.3HC	100	1.02	0	0.27	83	81	2.9
22A	1.0	3.81	3.1	0.3HC	100	0.99	0	0.27	86	72	2.7
23	1.25	4.87	3.2	0.3HC	100	1.02	0	0.27	82	84	3.1
24	1.5	5.65	3.1	0.3HC	100	1.02	0	0.27	79	57	3.2
25	1.75	6.46	3.0	0.3HC	100	1.02	0	0.27	76	42	2.7
27	0.75	2.83	3.1	0.6HC	95	1.07	0	0.27	76	50	1.3
28	1.0	3.74	3.0	0.6HC	98	1.07	0	0.27	76	53	1.9
29	1.25	4.66	3.0	0.6HC	100	1.07	0	0.27	75	49	2.2
30	1.5	5.89	3.2	0.6HC	100	1.07	0	0.27	76	51	2.9
31	1.0	13.04	10.6	0	100	1.04	0.30	0.06	80	43	5.6
31A	1.0	14.28	11.6	0	100	0.99	0	0.27	83	76	8.0

TABLE 26. TEST RESULTS - BENNETT MARK 6E (LIGHT OIL) AVERAGE VISCOSITY: 32 x 10^{-6} m^2/s

TEST CONDITIONS									TEST RESULTS		
Test no.	Tow speed m/s	Oil dist. rate $(m^3/s)x10^{-3}$	Slick thick. mm	Waves m x m	Enc. %	Door setting Bow	Mid	Aft	Rec. eff. %	Thru eff. %	Oil rec. rate $(m^3/s)x10^{-3}$
40A	0.5	1.91	3.1	0	100	0.97	0.36	0.06	59	76	1.5
45	0.5	1.89	3.1	0	100	0.91	0.36	0.08	68	88	1.6
41	1.0	3.82	3.1	0	100	0.99	0.36	0.06	52	43	1.6
41A	1.0	3.73	3.0	0	100	0.97	0	0.27	55	53	1.9
41B	1.0	3.84	3.1	0	100	0.97	0.25	0.15	57	41	1.6
42	1.5	5.72	3.1	0	100	0.97	0.15	0.27	52	27	2.0
43	0.75	3.36	3.6	0	100	0.97	0.25	0.27	60	76	2.6
43A	0.75	2.99	3.2	0	100	1.09	0.25	0.27	57	65	1.9
43B	0.75	2.80	3.0	0	100	0.97	0.25	0.27	55	73	1.9
44	1.0	3.69	3.0	0	100	1.09	1.15	1.27	50	39	1.4
50A	0.5	1.75	2.9	0	100	0.97	0	0.27	55	59	1.4
50B	0.5	2.31	3.7	0	100	0.97	0	0.27	71	81	1.9
51	0.75	2.83	3.1	0	100	0.97	0	0.27	60	90	2.6
51A	0.75	3.14	3.4	0	100	0.97	0	0.14	51	67	2.1
51C	0.75	2.77	3.0	0	100	0.97	0	0.15	58	71	1.9
52	1.0	4.08	3.3	0	100	0.91	0	0.14	64	63	2.6
52A	1.0	4.27	3.5	0	100	0.91	0	0.05	59	43	1.8
52B	1.0	4.15	3.4	0	100	0.94	0	0.05	63	65	2.7
53	1.25	4.24	2.8	0	100	0.93	0	0.03	68	54	2.2
53A	1.25	4.77	3.1	0	100	0.91	0	0.03	60	37	1.7
60	0.50	1.80	2.9	0.6HC	100	1.09	0	0.08	43	26	0.4
60A	0.50	1.76	2.9	0.6HC	100	1.04	0	0.16	30	17	0.3
61	0.75	2.86	3.1	0.6HC	100	1.52	0	0.27	40	12	0.3
61A	0.75	3.18	3.4	0.6HC	100	1.07	0	0.27	50	20	0.6
61B	0.75	2.89	1	1.6HC	100	1.07	0	0.27	52	27	0.7
70	0.75	2.80	3.0	0.3HC	100	1.02	0	0.27	55	41	1.1
70A	0.75	2.95	3.2	0.3HC	100	1.02	0	0.27	60	48	1.4
71	1.0	3.77	3.1	0.3HC	100	1.02	0	0.15	55	39	1.4
71A	1.0	4.36	3.5	0.3HC	100	1.02	0.05	0.15	40	38	1.6
72	0.50	4.06	6.5	0.3HC	100	1.02	0.05	0.27	58	59	2.4
72A	0.50	1.80	2.9	0.3HC	100	1.02	ND	0.27	51	59	1.1

Discussion

It was noted that the rotating absorbent belt performed best when near the water surface. The belt did not function well if it pushed the oil much below the water surface, causing oil and water to mix.

In operating the device, the major difficulty was with the bow and gill door settings. The adjustment of these openings was found to be critical to performance and a number of runs were spent determining their best settings.

Bow ramp depth determines the thickness of the oil/water cut when first entering the device. The depth must be set for each speed and wave condition. At speeds near 0.5 m/s, it was necessary to have a water cut of about 15 cm so that enough flow of water through the device could be induced to push the oil against the absorbent belt. At higher speeds, it was necessary to set this cut from 2.5 to 5 cm, adjusting the height as speed increased. In waves, it was necessary to ensure that the lowest trough of the wave flowed over the bow door.

The middle gill door is directly beneath the rear of the absorbent belt. If there is too much water flow through the skimmer, oil tends to be sucked through this door and out the bottom of the device. During calm water tests with heavy oil, an abrupt flow change within the skimmer was noted at 1.5 m/s. With the large middle gill door opening necessary for a slower tow speed, oil was being carried out of this gill door and lost. Performance improved only after the middle gill door was nearly closed.

Heavy oil tests in calm water were conducted with the bow trash grate in place. For heavy oil tests in waves, however, the trash grate caused oil emulsification in initial runs, and subsequent data runs were conducted without the grate. In both calm and wave conditions with light oil, the trash grate caused a great amount of oil emulsification, so the trash grate was removed for all light oil tests.

Major mechanical problems concerned the squeeze belt and scraper blade assemblies. Contact pressure between the open-mesh squeeze belt and absorbent belt was not sufficient to force oil through the mesh and into the collection sump. Additionally, the scraper blade, as originally installed, did not effectively wipe the squeeze belt of collected oil. Both assemblies worked better with heavy oil because of its tendency to form a thicker layer on the absorbent belt.

The following modifications were performed to achieve the best skimmer performance:

(1) Change squeeze belt to thinner material for light oil tests to eliminate oil trapped in thick weave of original belt.

(2) Install a squeegee over the scraper bar for light oil tests.

(3) Graduate bow ramp and gill door control rods to allow reproducible settings.

No other mechanical problems were of significance. The diesel prime mover, hydraulic pumps and motors were operated without incident throughout the two week test period. The polyester wool rotating collection belt showed no significant wear after the two weeks of testing. Figure 27 shows the scraper blade detail.

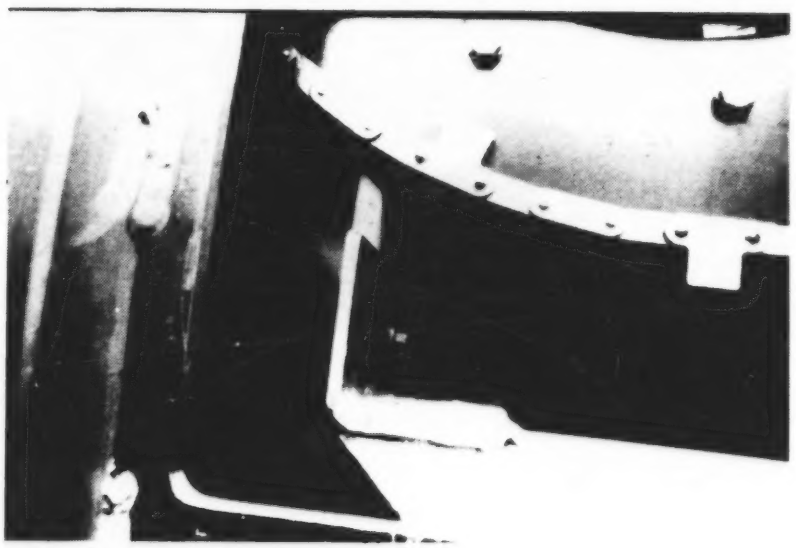


Figure 27. Scraper blade detail - BENNETT MARK 6E (squeeze) belt.

APPENDIX A

OHMSETT TEST FACILITY

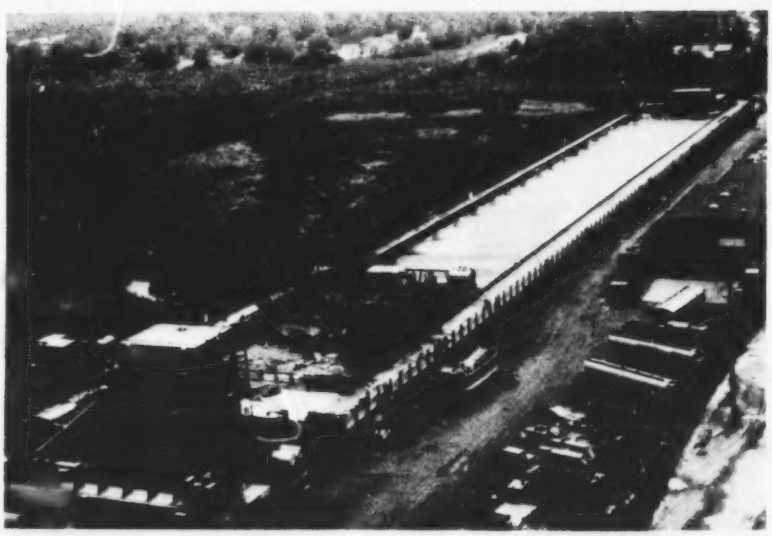


Figure A-1. OHMSETT test facility.

GENERAL

The U.S. Environmental Protection Agency is operating an Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) located in Leonardo, New Jersey (Figure A-1). This facility provides an environmentally safe place to conduct testing and development of devices and techniques for the control of oil and hazardous material spills.

The primary feature of the facility is a pile-supported, concrete tank with a water surface which is 203 metres long by 20 metres wide and which has a water depth of 2.4 metres. The tank can be filled with fresh or salt water. The tank is spanned by a bridge capable of exerting a force of up to 151 kilonewtons and towing floating equipment at speeds of up to 3 metres/second for at least 45 seconds. Slower speeds yield longer test runs. The towing bridge is equipped to lay oil or hazardous

materials on the surface of the water several metres ahead of the device being tested, so that reproducible thicknesses and widths of the test fluids can be achieved with minimum interference by wind.

The principal systems of the tank include a wave generator, beach, and a filter system. The wave generator and absorber beach have capabilities of producing regular waves of up to 0.7 metre in height and 28.0 metres in length, as well as a series of high (up to 1.2 metres), reflecting, complex waves meant to simulate the water surface of a harbor or sea. The tank water is clarified by recirculation through a 0.13 cubic metre/second diatomaceous earth filter system in order to permit full use of a sophisticated underwater photography and video imagery system, and to remove the hydrocarbons that enter the tank water as a result of testing. The towing bridge has a built-in skimming board which can move oil onto the North end of the tank for cleanup and recycling.

When the tank must be emptied for maintenance purposes, the entire water volume of 9842 cubic metres is filtered and treated until it meets all applicable State and Federal water quality standards before being discharged. Additional specialized treatment may be used whenever hazardous materials are used for tests. One such device is a trailer-mounted carbon treatment unit for removing organic materials from the water.

Testing at the facility is served from a 650 square metres building adjacent to the tank. This building houses offices, a quality control laboratory (which is very important since test fluids and tank water are both recycled), a small machine shop, and an equipment preparation area.

This government-owned, contractor-operated facility is available for testing purposes on a cost-reimbursable basis. The operating contractor, Mason & Hanger-Silas Mason Co., Inc., provides a permanent staff of fourteen multi-disciplinary personnel. The U.S. Environmental Protection Agency provides expertise in the areas of spill control technology and overall project direction.

For additional information, contact: John S. Farlow, OHMSETT Project Officer, U.S. Environmental Protection Agency, Research and Development, IERL-Ci, Edison, New Jersey 08817, 201-321-6631.

SPECIAL EQUIPMENT

During the 8 week OHMSETT Interagency Test Committee (OITC) test program, some equipment changes were made to increase the ease and quality of data collection. Although these changes were the results of working with the four oil skimmers tested during the OITC 1977 season, it is felt they could be of use in future OHMSETT test programs. The modifications are:

(1) Use of tape recorders by the Project and Test Engineers.
(2) Use of a stadium-type lighted stopclock on control tower.

Small portable tape recorders were very useful in capturing detailed performance information and impressions of the Test Engineer and the OITC Project Engineer during the course of individual test runs. When transcribed, this record was invaluable for explaining data differences between runs and in documenting key behavior patterns of the skimmer under test. This method of data recording was especially useful during rainy weather when keeping accurate hand-written notes would have been difficult. A system of remote microphones all hard-wired to a central tape recorder was found to be impractical as the engineers using these recorders had to move about more than cord restraints would allow.

A labor saving of one technician was possible during the Cyclonet 050 tests following the installation of a large, stadium-type lighted stopclock mounted on a control tower. This stopclock is visible from the skimmer and all portions of the tow and auxiliary bridges and was used to coordinate a number of different events such as oil slick distribution, pump activation aboard the skimmer, and the beginning of sample taking aboard the skimmer. The number and conditions of the next test run could be quickly displayed so that all OHMSETT technicians could begin at once to change tow speed, wave, and oil distribution settings as needed.

APPENDIX B

SAMPLING PROCEDURES

Discrete sampling, that is, continuous sampling from a small discharge port at the outlet of the skimmer pump at various time intervals, was utilized to determine the presence of steady state in the operation of the skimmers. Although discrete samples provide the level of detail necessary to determine steady state operation, the collection and analysis of the many samples required extensive lab time. Due to the extensive experience during this test program with Discrete versus Composite (standard OHMSETT) sampling procedures, the following general conclusions can be drawn:

(1) Discrete samples are necessary for the first series of runs for each test oil to determine the transient response time of the skimmer before steady state operation is established.

(2) For transient periods on the order of 1/5 of the total test time, the Composite sample, taken once at the end of the run from the total oil/water mixture collected during the run, is of sufficient accuracy and Discrete sampling is not required.

(3) A method of Composite sampling which appears to require less time to perform than the current OHMSETT standard procedure and should be considered for future OHMSETT programs, is termed the Small Volume Composite sample. In this procedure, a continuous, single sample is obtained for each test run by slowly bleeding the oil/water mixture from the pump discharge into a sample bottle. This smaller sample, about 2 litre size, can be more easily analyzed than the larger 1.89 m^3 barrels which are difficult to emulsify uniformly and, for light test oil, may settle out quickly after being agitated, thus making the obtaining of a representative grab sample difficult.

(4) Selection of one of the above three sampling procedures for a given skimmer can only be made after comparing the results of all three during initial shakedown runs. In the order of decreasing desirability, the sampling procedures are (maximizing the number of data runs):

--Small Volume Composite, (1) above
--Composite, (2) above
--Discrete, (3) above

Data presented in this report are derived from the careful analysis of both discrete and composite samples. The intent was to present the the overall trends of device performance as they were observed and measured at OHMSETT. As an example, in the case of the Oil Mop ZRV, the highest RE from discrete or composite samples was utilized if, and only if, they agreed by at least 10%. Otherwise, the composite sample was felt to be more respresentative and therefore included in the data set. Subsequent calculations of TE and ORR were based on the results of the above conditional statement. Figure B-1 represents the comparison of Discrete and Composite sample results.

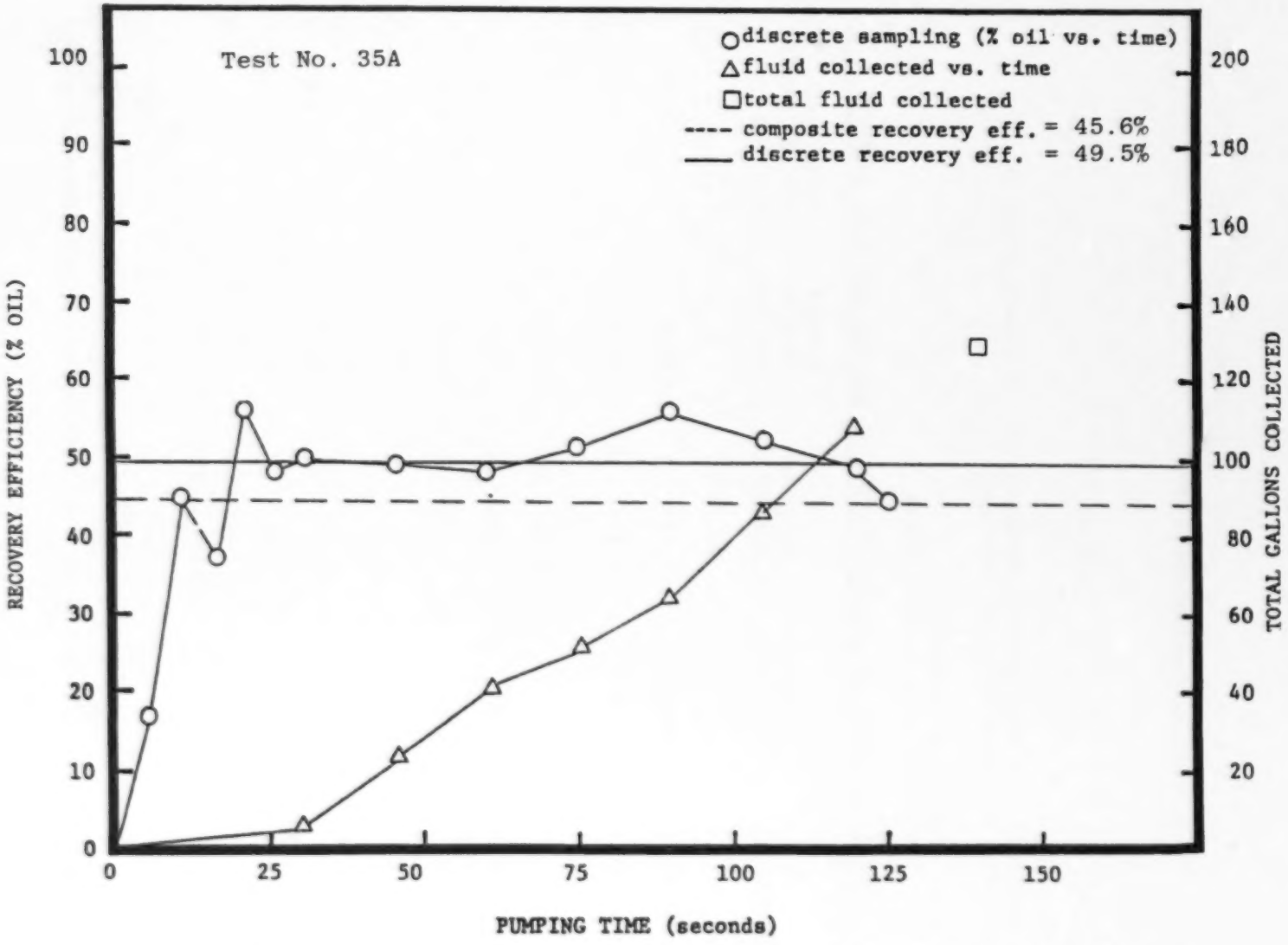


Figure B-1. Skimmer comparison of DISCRETE and COMPOSITE oil/water sampling OIL MOP ZRV.

APPENDIX C

Differences in the physical properties of the same type oil as indicated in Table C-1 below are the result of:

(1) temperature variation
(2) contamination and reprocessing

TABLE C-1. RANGE OF TEST OIL PROPERTIES FOR THE 1977 OITC SERIES

Designation	Viscosity $x10^{-6}m^2/s$	Specific gravity	Surface tension $x10^{-3}N/m$	Interfacial surface tension $x10^{-3}N/m$
		OIL MOP		
Circo Heavy	3000	.937	38.1	31.9
Circo Light	9	.886	28.5	28.6
		CYCLONET 050		
Circo Heavy	550	.938	38.7	9.6
Circo Light	22	.891	34.6	9.6
		CLOWSOR		
Circo Heavy	1900	.941	38.0	8.4
Circo Light	14	.897	34.7	5.5
		BENNETT MARK 6E		
Circo Heavy	3200	.932	35.1	19.7
Circo Light	32	.905	32.7	7.3

These four programs were conducted separately at OHMSETT during the 1977 test season. As a result, tank water temperature was different for each test series. Since it is felt that the oil temperature as it is encountered by a device is the same as water temperature, significant oil property differences result.

Oil property variations as a result of mixing contamination and reprocessing have been documented previously at OHMSETT. Performing a 100% purge of the main bridge oil storage, transfer, and distribution system while transferring oils during a given test program is prohibited by time and cost limitations. This results in the mixing of slight but significant amounts of oils and thus variations in measured properties. Additionally, the reprocessing of test oils by vacuum distillation contributes to specific property changes. These effects are currently being investigated at OHMSETT.

Laboratory methods are continually evaluated via the control chart method as presented by the American Society for Testing and Materials, Committee E-11. Statements on precision and accuracy are available at OHMSETT.

APPENDIX D

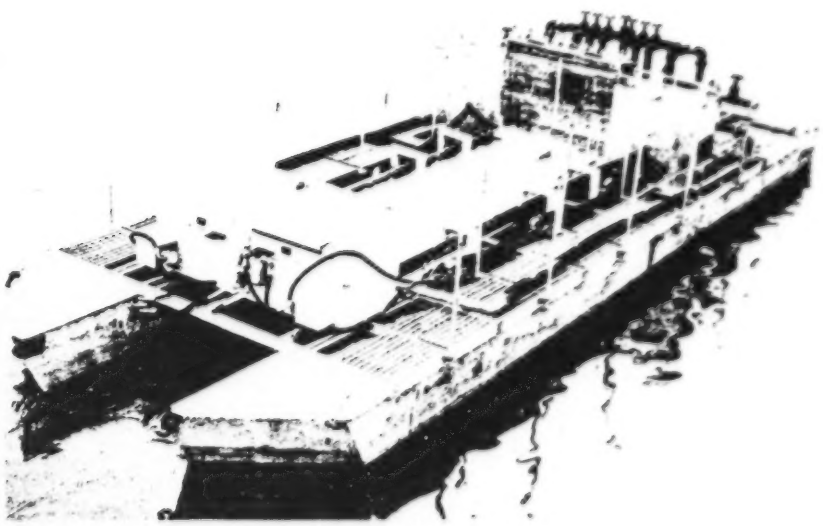
SKIMMER BROCHURES

OIL MOP INC

DYNAMIC SKIMMER

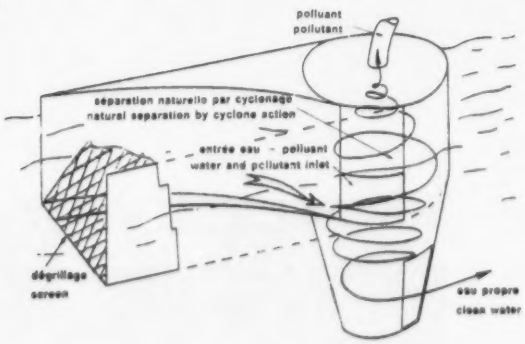
PAT PENDING

SPECIFICATIONS



RECOVERY RATE	250 BBL/HR
RECOVERY SPEED	6 KNOTS
STORAGE CAPACITY	2400 GAL. 9,080L
PUMPING CAPACITY	400 BBL/HR
TRAVEL SPL D	15 KNOTS
LENGTH	38' 2" 11.6M
WIDTH	12' 2" 3.7M
SHIPPING WEIGHT	20,000 LB. 9,072KG

CYCLONET 050



technical particulars

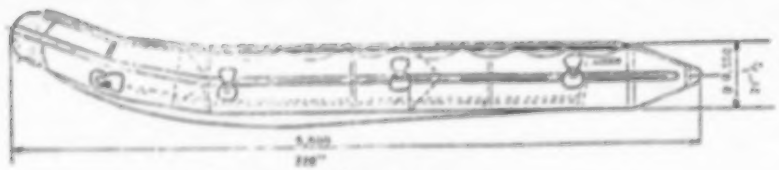
The unit :

Body width	0.50 m
Length	1.50 m
Height	1.00 m
Average draught	0.85 m
Weight	80 kg (approx.)

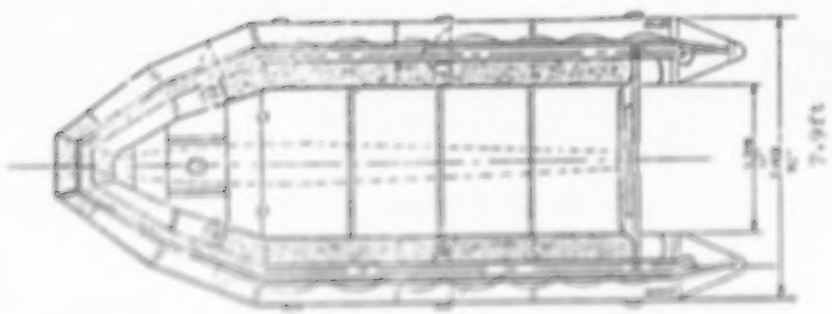
Operating speed 0.5 - 5 knots

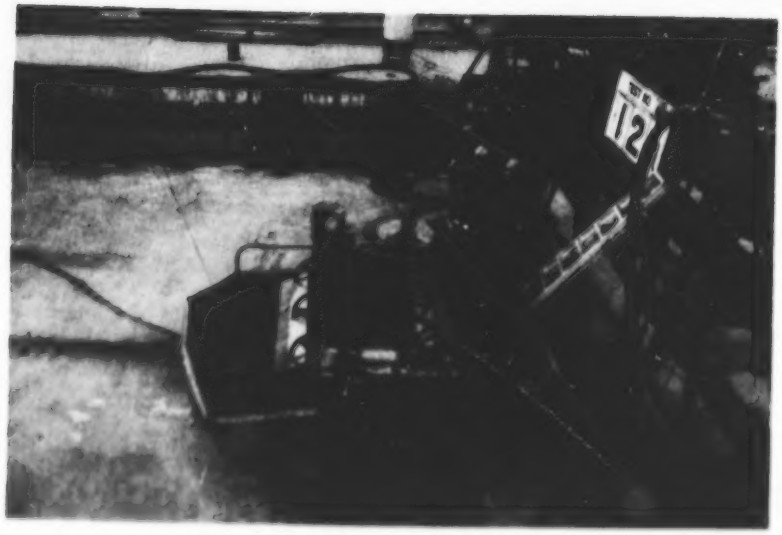
Power input for two units 8 h.p. at 5 knots

ZODIAC Inflatable Boat



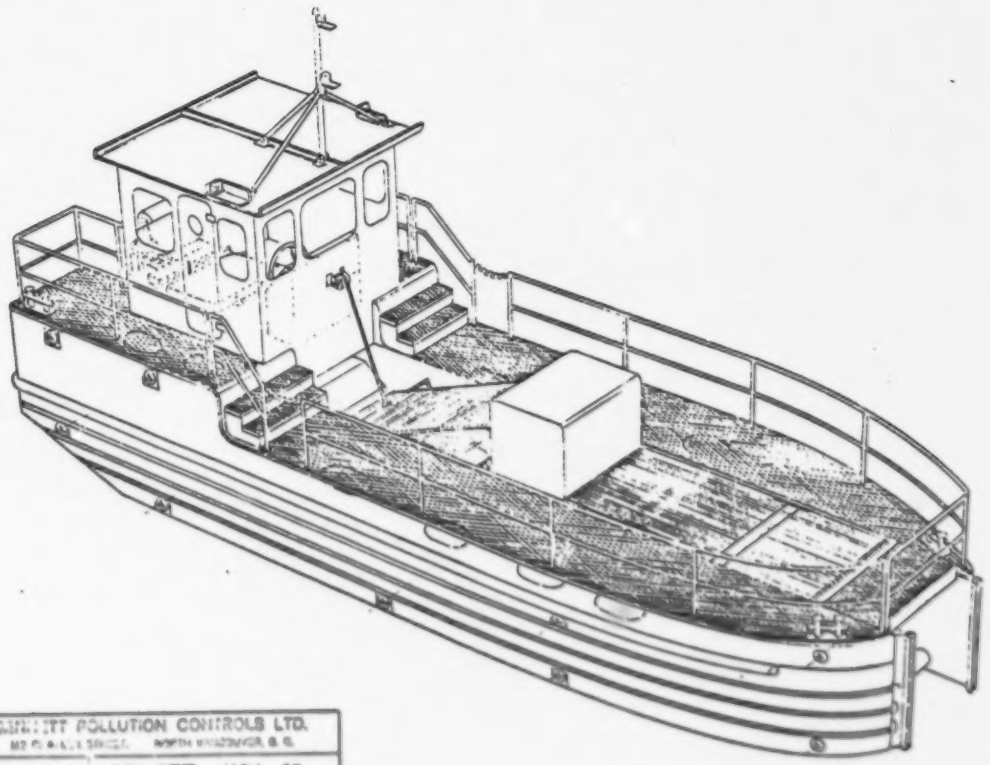
19 ft





CLOWSOR

Length	Width	Height
2.3 m	3.03 m	1.2 m



BENNETT POLLUTION CONTROLS LTD.

BENNETT MARK 6E SKIMMER

BENNETT MARK 6 E OIL SKIMMER.

Length (overall)	37ft.0in.	11.3 m
Length (waterline)	37ft.0in.	11.3 m
Beam (moulded)	13ft. 7in.	4.1 m
Depth (moulded)	4ft. 0in.	1.22 m.
Displacement (loaded)	22.7 tons	23.1 tonnes
Freeboard (loaded)	18 ins.	
Freeboard (light)	24ins.	
Nett tonnage (tons of 100 ft^3)	7.35	
Free swept width	4 ft. 6ins.	
Width between hulls	4 ft. 0ins.	
Shipping Weight.	29,500 lbs.	13,380 kilogrammes.

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